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INFLUENCE OF LONG-TERM SOIL AMENDMENTS ON PHYSICAL PROPERTIES OF CHEROKEE SILT LOAM

by

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B.S., Department of Soil Science, College of Agriculture,
University of Baghdad, Iraq, 1974

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

Kansas State University
Manhattan, Kansas

1978

Approved by:

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ACKNOWLEDGMENTS

The author wishes to express sincere gratitude and appreciation to his Major Professor, Dr. L.R. Stone, Assistant Professor of Soil Physics, for his guidance and indispensible help throughout this study.

The author also wishes to express his sincere appreciation to Dr. W.L. Powers, and Dr. J.A. Hobbs for their serving on his committee and for unrestricted use of their laboratory equipment.

He would like to thank Dr. K.E. Kemp, Assistant Professor of Statistics for his assistance in statistical analysis of the data. He would also like to thank Professor V.H. Peterson, for his assistance in obtaining the experiment history. Appreciation goes to Kenneth Kelley, Southeast Kansas Branch Agr. Expt. Sta., for the grain sorghum yield data and field plot sampling assistance. Appreciation is due Mike Sauber for his assistance in drawings and graphing the data.

Many thanks go to my mother and father and all the relatives for their patience, support, and encouragement through the entire period of study. Appreciation is aldo due the Republic of Iraq Government for providing the author with a scholarship.

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INTRODUCTION

Soil productivity is a function of cropping systems, management practices (including fertilizer applications), and tillage practices. High soil productivity implies that large yields can be obtained in relation to the labor required or to the cost of production. Some soils differ in their productivity from one crop to another and may require different management practices for different crops.

The management practices may include tillage operations, applications of fertilizer and/or lime, providing satisfactory erosion-control, establishing drainage, and irrigation. Soil fertility is included in the concept of soil productivity, but refers only to the content, balance, and availability of chemical compounds in the soil that are necessary for plant growth.

The most direct reason for managing physical conditions of soils is to provide a physical environment that is as favorable to crop growth as can be achieved. The factors to be considered are moisture, aeration, temperature, and resistance to root penetration to the depth normally explored by the given crop. The soil physical properties have interacting influences upon plant growth and it is difficult to separate the effect of each from the others. For example, soil compaction affects soil-water relations, soil aeration, soil aggregation, soil bulk density, and soil impedance to

root growth.

There are also relationships between soil productivity and soil physical properties which are related to the environmental action on soil material, including added soil amendment materials. Using proper soil management practices can increase availability of nutrients and improve the soil physical condition, which in turn influences the availability of nutrients and plant growth.

Lime and manure have long been considered practical solutions to some physical property problems, including soil structure. Baver et al. (4) stated that field and laboratory data did not confirm any direct effect of lime on soil structure. However, lime is recognized as a promoting factor in generating development of vegetation and in production of organic matter, which usually causes improvement of soil structure. Many investigators (5, 20, 28, 29, 50) have obtained no beneficial response on soil physical properties from manure and have attributed crop responses to the plant nutrients in the manure. Others (10, 11) have noted significant influences of manure on soil structure.

Lutz (25) noted significant influences of phosphate fertilizers on soil tilth. Phosphorous applications decreased soil strength and increased water holding capacity. They attributed this response to the replacement of hydroxyl (OH^-) ions by phosphate ions on the edges of the clay particles which caused aggregation of particles.

The study reported on in this thesis was initiated as a

crop rotation and soil amendment study in 1923. The treatments were continued through 1972. The study was located at the Columbus Field of the Southeast Kansas Branch Experiment Station. Soil amendment materials were lime, barnyard manure, superphosphate, rock phosphate, and potash. A crop rotation scheme was superimposed and used as a multiple year rotation on all plots. Due to treatment similarities and time required for sample analyses, the samples were collected from five treatments (of the total 12) and from three blocks (of the total 6).

The objectives of this study were:

1. To evaluate the effectiveness of long-term applications of amendment materials in influencing the physical condition of a soil.

2. To compare the effects of various soil amendment materials on selected physical properties of Cherokee silt loam.

3. To compare the residual effects of amendment materials on grain sorghum yields.

REVIEW OF LITERATURE

Soil physical properties are important factors in the plant growth environment. Most physical properties of soil are relatively unsteady with time due to tillage operations, management practices, and cropping systems (rotations). Many investigators have studied various physical properties of soil in assessing the root zone environment.

Soil aggregation has been studied by many investigators. Alderfere and Merkle (1) reported that a rotation of corn, oats, wheat, and clover over a period of 58 years caused breakdown cf aggregates as compared with adjacent sod land. They concluded from their studies: (a) farm manure produced definite physical improvement, (b) lime did not alter the structural conditions, and (c) in treatments where phosphorous and potasium were applied with various sources of organic materials, structural stability was closely correlated with the organic materials rather than the phosphorous and potasium applications.

A study of the effect of various cropping and fertility practices on structure and exchangeable status by Zobler and Kardos (51) showed that annually cropped wheat plots were found to possess less stable macroaggregates (aggregates>1 mm) than those alternately cropped and fallowed. The study also pointed out that the microaggregates (aggregates<1 mm) of the annually cropped plots appeared to be more stable as a result of the presence of more organic colloids.

A four-year study on the effect of crop, lime, manure, and fertilizer on macroaggregates by Elson (11) showed that the soil under wheat had the same percentage of macroaggregates as that under corn, while clover showed a 10.3% increase over wheat and grass showed a 9.1% increase over clover. He reported that the treated plots (manure and fertilizer) had 8% more macroaggregates than the untreated ones, while the manured plots had 15% more than the fertilized. He pointed out that the relationship of liming to aggregation was associated with a stimulation of microbiological activity and formation of organic binding material in the soil. It has been reported that lime plus manure increases the percentage of water stable aggregates (1, 4).

A study of lime effects on continuous no-tillage and conventionally tilled corn over an 8-year period by Moschler et al. (32) showed that lime was essential for highest yields with both tillage methods but the yield increase due to surface-applied lime in no-tillage culture averaged 31.3% compared with a 13.5% yield increase due to incorporated lime in conventional tillage culture. Associated with the large yield increase from lime in the no-tillage culture were: (a) a higher pH in the 0 to 10 cm soil layer (averaging 6.4 in no-tillage compared with 6.0 in conventional tillage) in the eighth year; (b) a large increase in exchangeable Ca^{++} and a reduction in exchangeable Al^{+++} in the 0 to 10 cm layer; and (c) the water use efficiency for increased corn yield due to lime in no-tillage plots was almost three times that in conventional

tillage plots.

A study of the effect of cropping and manure applications on some soil physical properties in eastern Nebraska by Bertramsom and Rhoades (5) showed that the addition of manure had no appreciable effects on the consistency limits, moisture equivalent, bulk density, or aggregation. They reported that the cultivated soil had only 12.8% as many aggregates>0.5 mm, as were found for uncultivated soil.

Elson (10) showed a highly significant correlation (r= 0.696) between percentage of soil aggregates>1 mm and organic matter content. The organic matter (O.M.) content and the percentage of aggregates were significantly greater for the treated subplots (fertilized and manured) than for untreated ones.

In studying the influence of management practices on soil physical properties, Tanchandrphongs and Davidson (43) reported that soil aggregation under stubble mulching was greater than under clean tillage. Laws and Evans (23) studied the effect of long-term cultivation on some physical and chemical properties of two Rendzina soils and found the yields declined considerably as a result of 50 to 90 years of cropping to cotton and other cultivated crops. Most crops exhibited one or more nutrient deficiency symptoms, and unusual difficulty was encountered in correcting mineral deficiency with commercial fertilizers. These facts suggested that poor soil structure was a limiting factor in crop production. They also found that the virgin soil contained considerably more aggregates of the

2 to 5 mm class and 1 to 2 mm class than the cultivated soils. The quantity of 2 to 5 mm aggregates decreased with depth while the 1 to 2 mm aggregates increased. This was true in both virgin and cultivated soil. The cultivated soil contained the most 0.25 to 1 mm aggregates. The state of aggregation (5 mm $>$ agg. $>$ 0.25mm) was better for virgin soil than for cultivated soil at all depths.

In studying the influence of long-term fertility management practices on chemical and physical properties of Fargo clay, Young et al. (50) reported that the mean weight-diameter (an index of aggregation) after wet-sieving was not influenced significantly by the past fertility treatments. Klute and Jacob (20) studying the result of long-term O.M. additions, found the stability of aggregates in the 2 to 5 mm fraction separated from air dry soil was significantly greater at the higher O.M. levels; 18,160 kg/ha manure per four years and complete fertilizer were necessary to bring about a significant increase of stability as compared to no-manure plots.

A study of the effect of cropping practices on aggregation and some other physical properties by Johnston et al. (17) showed that the size distribution of aggregates was influenced by the cropping systems. The amount of large-size aggregates decreased in the following order: bluegrass, clover, oats, rotation corn, and continuous corn. Red clover maintained a loose, granular structure, while continuous corn left the soil cloddy and difficult to work.

Schaller and Stockinger (38) used five ways of expressing

aggregation data. They were: percent aggregates greater than 2 mm, 1 mm, and 0.25 mm; geometric mean, and mean weight-diameter. To determine the advantages and disadvantages of the several indices, aggregation results obtained by the Yoder method (wet-sieving analysis) on several hundred soil samples from three locations in Iowa were compared. Correlation coefficients were obtained between the mean weight-diameter and the percent of aggregates>2mm, >1mm, and >0.25 mm, and the geometric mean. The geometric mean was also correlated with the three size separates. The results indicated that the single size fraction such as the >2mm or >1mm can be satisfactorily used to express soil aggregation. The percentages of aggregates using wet-sieving techniques have been used by many investigators (5, 10, 11, 23, 38, 43).

Organic matter is a major factor influencing the physical properties of soil. Bulk density, aggregate stability, soil compactibility, soil water retention, and erodability are affected directly or indirectly by the soil organic matter content (20). The soil organic matter content is not stable with time in cultivated soils. It is affected by cropping systems, management practices, and tillage operations.

Unger (47) found that wheat stubble mulching resulted in higher O.M. values than clean tillage, and the wheat-fallow cropping system had lower O.M. contents than continuous wheat for comparable tillage practices. Davidson et al. (8) reported that continuous cotton resulted in lower O.M. content than continuous lespedeza in the surface soil. Tanchandrphongs

and Davidson (43) noted that the O.M. content in the surface soil was significantly greater under stubble mulching than under clean tillage.

Laws and Evans (23) in a study of long-term cultivation, remarked that soil cultivation for a period of 50 to 90 years caused a decrease in organic matter and total nitrogen.

A study of the effect of cropping practices on organic matter content by Johnston et al. (17) showed that under continuous corn the percent organic matter content had decreased from 3.39% in 1931 to 2.86% in 1942. No significant difference was found in the organic matter content between continuous bluegrass and a rotation of corn, oats, and clover during those years. In studying the influence of long-term fertility management practices on organic matter, Young et al. (50) cited the following results: (a) with a long period of fertility management practices, the organic matter content declined in all plots, and the rate of decline was more rapid in check plots than those which received manure or residues (barley and wheat straw). (b) Plots which received phosphorus in addition to manure or residues lost more O.M. than those which received only manure or residues and that fact was probably due to the possibility that phosphorus stimulated microbial activity thus causing faster decomposition of organic matter compounds. (c) Lime had no influence on maintance of O.M., but it appeared that potash helped in maintenance.

In a study of cumulative effects of manure and nitrogen on continuous corn with clay soil, McIntosh and Varney (29)

reported that an annual application of about 44,000 kg/ha of fresh dairy cattle manure was needed to maintain the soil organic matter content. Percentage of organic carbon in check plots decreased from 5.20 to 4.28% in the five years of continuous corn with an average loss of about 0.18% per year. Soil test results showed that phosphorous (P) from manure was more available than fertilizer P; 119 kg/ha of P from manure increased soil test P about the same as 480 kg/ha of P from fertilizer. However, potassium (K), either from manure or fertilizer, was readily fixed by soil and 414 kg/ha of K was needed to keep an appreciable level of K. Manure application up to 44,000 kg/ha did not have enough calcium or magnesium to maintain initial levels in the soil.

It is frequently thought that compaction layers are more common in medium-textured soil and that with manipulation and time, the finer particles move down through the profile producing a pan. An attempt was made by Davidson et al. (8) to determine if there was any accumulation of particles of a given size in the zone of compaction owing to cropping practices. They reported that the differences in particle size at any one depth between cropping systems were not significant at the 5% level for any of the soil separates.

Changes in soil bulk density are influenced by soil texture, moisture, O.M. content, and load. Eschner et al. (12) reported that the fine-textured soils have lower bulk densities than the coarse-textured soils. Curtis and Post (7) stated that in stony forest soils, bulk density for A and B horizons may be

estimated from the percent of organic matter with a degree of accuracy satisfactory for most purposes. Klute and Jacob (20) found that applying manure (resulting in a range of soil O.M. from 2.5 to 5%) caused a significant decrease in bulk density. Davidson et al. (8) studied the bulk density at various depths after 24 years of continuous cotton and continuous lespedeza. They found the bulk density was significantly different between treatments in the 5.1 to 12.7 cm and 12.7 to 20.3 cm layers at the 5% and 1% levels, respectively. Continuous cotton resulted in lower soil O.M. and higher bulk density than continuous lespedeza in the 12.7 to 20.3 cm layer. Tanchadrphongs and Davidson (43) studied soil bulk density as influenced by clean tillage and stubble mulching. They found that the bulk density under clean tillage was significantly greater than under stubble mulching in the 23 to 30 cm soil layer, with no soil compaction noted from stubble mulching.

Davidson et al. (8) found the following: (a) the maximum compaction for continuous cotton>cotton-barley rotation> continuous lespedeza; and (b) the optimum water content for compaction for continuous cotton<cotton-barley rotation< continuous lespedeza. They reported that the differences were related to the cropping systems which influenced the organic matter content.

Young et al. (50) reported that the bulk density of fertilized plots was slightly less than that of non-fertilized plots. Larson (22) in studying the soil parameters for evaluating tillage needs and operations reported that bulk density can

be used as a measure of oxygen availability, soil compaction, and mechanical impedance.

Soil consistency describes the evident characteristics of the soil at various moisture contents when influenced by physical forces of cohesion and adhesion. Soil consistency varies with texture, structure, organic matter, percentage of colloidal material, shape and type of clay mineral, and soil water content. Several consistency terms express the various conditions of the soil mass, such as hardness, friability, and plasticity. Since the plasticity is a function of the finer soil fraction, soils possess different plasticity according to the amount of clay.

Baver (4) reported that an increase in the percentage of clay causes plastic limits to be higher on the moisture scale and increases the plasticity number. Skempton (40) showed that the plasticity index was related to the percentage of clay in different clay systems which determines the amount of the surface that is available for water adsorption. He also reported that only those minerals that have a platy or sheet-like structure exhibit plasticity.

Baver's studies (2, 3) of the factors affecting the Atterberg limits pointed out the following:

a - The size and shape of particles affects the plasticity measurements. The fine and plate-like colloidal particles increase both plasticity limits.

b - The clay content and type of clay affect plasticity limits. Clay increases upper plastic limit at a greater rate than lower plastic limit which increases the plasticity number.

c - Exchangeable cations: the divalent cations tend to increase the plasticity number and both plastic limits, with the rate of UPL increase greater than the LPL increase. Potassium ions decrease plasticity number and both upper and lower plastic limits, with the rate of UPL decrease greater than the LPL decrease. Sodium ions increase plasticity number but lower both plastic limits. Increasing PN with sodium ions is due to the decreasing rate of UPL being less than that for LPL.

d - Organic matter causes plasticity to occur at higher moisture levels but does not materially affect the magnitude of plasticity (plasticity number).

The greater the amount of water taken up by the inter-layer spaces, the greater the amount of water needed to increase the thickness of the film to give a lubrication action (30).

Potassium (K^+) ions are fixed between the inner layers when the expanding-lattice clay are dried (4). They hold the layers together, resulting in the formation of illitic-type structures which decreases the water-absorbing properties of the clay mineral. The plasticity of K-saturated montmorillon-ite is analogous to that of illite (37).

The polyvalent cations tend to hold the expanding lattices together and there is little development of water layers be-tween them. Calcium ion has a much higher hydration energy than the sodium monovalent ion. The higher hydration energies of the divalent cations should cause a raising of the Atterberg limits (4).

Removal or oxidation of organic matter lowers plasticity limits (4). A study by White (49) showed that the plasticity index was not materially changed by oxidation of the O.M. Because the cultivation of virgin soil decreases the organic matter content, the plasticity limits will be higher in virgin soil than in cultivated soil.

In a study of the relationship of Atterberg limits to some other properties of Illinois soils by Odell et al. (33), multiple correlation coefficients of 0.959, 0.887, and 0.938 were obtained between UPL, LPL, and PN, respectively, and three soil properties (percent organic carbon, percent clay, and percent montmorillonite in the clay separate). The coefficients indicate a close relationship between Atterberg limits and the three soil properties. Lower, but highly significant correlations were obtained between each of the Atterberg limits and the cation exchange capacity; and a combination of percent of organic carbon and percent of clay.

A study of the effect of cropping and manure applications on some soil physical properties in eastern Nebraska by Bertramson and Rhoades (5) showed the following results:

a - The addition of manure had no appreciable influence on the soil consistency values.

b - For the surface 15 cm, the values for uncultivated soil exceeded the average values for the cropped soil as follows:

1 - the upper plastic limit	10
2 - the lower plastic limit	7

3 - the plasticity number 3

Water retained by soil has been studied by many investigators and for many purposes. A study of the influence of long-term fertility management practices on the chemical and physical properties of Fargo clay by Young et al. (50) showed that the total pore volume as represented by percent moisture at saturation was not significantly related to the past fertility treatments. Soil cores from treated plots contained less water at -50 cm of water pressure potential than did those from the check plots. This was true for both the 3 to 10 cm and 10 to 18 cm layers. The difference between the manured and check plots was statistically significant (5% level) while that between residues (barley and wheat straw) and check was not. This was possibly a reflection of the fact that fewer comparisons were involved in the latter case. The same trends in moisture content at -60 cm of water pressure potential were observed but treatment differences were not as large and were significantly different (5% level) only in the 10 to 18 cm layer. It appeared that manure and residues have been of some values in maintaining air space porosity.

Bertramson and Rhoades (5) pointed out in a comparison of moisture data for manured and unmanured soils that the manure had a small but insignificant effect on moisture equivalent (water content at -1/3 bars pressure potential), available water capacity, and maximum water capacity. There was no difference between the hygroscopic coefficients (the moisture coefficients at which water is held tightly to the surface of

the soil particles by adsorption forces) for these soils. A striking difference was again noted between the cultivated (manured and unmanured) and uncultivated soils. The uncultivated soils had a moisture equivalent approximately 7% greater than the cultivated, a hygroscopic coefficient 1% greater, available water capacity (-1/3 to -15 bars pressure potential) 6% greater, and a maximum water capacity (0 to -15 bars pressure potential) about 16% greater.

A study of the effects of long-term cultivation on some physical and chemical properties of two Rendzina soils by Laws and Evans (23) showed that cultivation for 50 to 90 years had decreased the amount of water drained under -30 cm of water pressure potential in Houston black clay. They also showed that the air space of undisturbed soil cores measured in a pressure pycnometer at the same field moisture content was 50 to 100% greater for virgin soil than for cultivated soil. This was true at all depths sampled, indicating that cultivation of soil decreases soil porosity by decreasing organic matter and soil aggregation.

A study of the effect of phosphorus on soil water retention by Lutz et al. (25) showed that the use of phosphate fertilizers increased the amount of water present in the soil and facilitated tillage. The laboratory studies showed that phosphorus appreciably increased the water holding properties of soils. This was found to be directly related to the increase in the negative charge of the soil particles and the charge was closely related to the Al-phosphate/Fe-phosphate

ratio. Moisture retention was studied for compacted and adjacent soil layers in coarse-textured soils as a physical parameter for knowing the physical properties of compacted soil (31). They showed that the moisture retention characteristics of the samples appeared to be closely related to the clay content.

Well-developed plow pans limit root penetration and air and water movement. The artificial pans are characterized by high bulk densities and low noncapillary porosity. Many experiments have been done to show the effects of soil compaction on soil physical properties and plant growth. Flocker et al. (14) found that the porosity of the soils affected by compaction limited the height of tomato plants. In a study by Gill and Miller (15), root growth of corn seedlings was decreased by increasing the mechanical impedance and by decreasing the percentage of oxygen in the soil atmosphere. Biehmeyer and Hendrickson (48) concluded from their study that the restriction in the penetration of sunflower roots was mainly due to mechanical impedance produced by a predominance of small pores. Hemsath and Mazurak (16) found that the root length of sorghum decreased as the soil strength increased and there was no root growth after a critical value of penetration resistance (19 bars). Soil compaction has many effects on soil-water-plant relationships. A study by Phillips and Kirkham (35) showed that soil compaction markedly reduced growth and yield of corn because the soil compacted layers may be unfavorable to root growth because of lack of moisture, or oxygen,

and/or because of the mechanical impedance to root penetration in those layers. Another study by Meredith and Patrick (26) showed that when bulk density increased, the root penetration decreased, and the decrease was greater in coarse-textured soils than in fine-textured soils. They also found that compaction decreased the soil porosity so the plant root penetration was decreased.

Penetrometers are used as an indirect measure of the resistance to root penetration: the greater the penetrometer reading, the greater the resistance, and the less the expected root penetration.

A study of the effect of bulk density, soil moisture, and soil strength on cotton root penetration by Taylor and Gardner (44) showed the following: (a) at a given soil bulk density, taproots had greater probability of penetration, and the soil had less strength at higher soil water pressure potentials (higher water contents) than at lower soil water pressure potentials (lower water content). (b) At a given pressure potential, the greater the soil bulk density, the greater the soil strength, and the less the root penetration. (c) There was a highly significant linear correlation ($r=-0.96$) between soil strength and the percentage of root penetration, and a smaller correlation coefficient ($r=-0.59$) between soil bulk density and root penetration. Thus, soil strength is better than bulk density in assessing root penetration. That increasing soil bulk density decreases root penetration was found by Phillips and Kirkham (36).

A study of the influence of soil compaction on the development of sugar cane roots by Trouse and Humbert (46) showed that an increase in bulk density decreased root growth by the following effects:

a - The percent of air volume decreased.

b - The percent of water volume increased.

These were caused by the following reasons:

1. The noncapillary porosity decreased.

2. The smaller the pore size caused by compaction, the greater the amount of water held by capillary forces.

There are specific values of bulk density and soil strength in which no root growth can occur and these values are variable with different plants. Taylor and Gardner (44) reported a critical bulk density of 1.85 g/cm^3 and a critical soil strength of 29.1 bars for cotton taproots.

A study of the influence of mechanical impedance on rice seedling roots by Kar and Varade (18) showed that the maximum rice root growth occurred when the soil bulk density and penetration pressure were 1.6 g/cm^3 and 35.4 bars, respectively. A penetration resistance of 70.8 bars was found to stop rice root penetration and growth. They also found that the rice root growth under saturated conditions was more significantly related to bulk density than to soil strength. That result was concluded from the correlation coefficients between root penetration and bulk density ($r = -0.98$) and between root penetration and soil strength ($r = -0.83$).

Shaw et al. (39) reported that penetrometers have been

used successfully by many investigators and the penetrometer readings are affected by soil texture, amount, and character of plant roots. They also reported that soil moisture is the dominant factor influencing the force required to push a probe into the soil. Under field conditions there is no simple relationship between soil moisture and penetrometer readings. In a small area of apparently uniform soil growing an apparently uniform crop, porosity and root differences were of sufficient magnitude to have large effects on measurements.

A study of soil penetrability by Klute and Jacob (20) showed that the penetrability of the soil was not affected by manure treatments. Highly significant decreases in penetrability were found due to compaction in the 0 to 13 cm layer. The penetrability of the 15 to 23 cm zone was not affected by compaction or the manure treatments. In a short-term experiment of root elongation rates of cotton and peanuts, Taylor and Ratliff (45) showed that the root elongation rates of cotton and peanuts decreased as soil strengths (measured with a penetrometer) increased. With both cotton and peanuts, top weight and lengths increased as soil water pressure potential increased.

EXPERIMENT HISTORY

Introduction

A crop rotation and soil amendment study was initiated in 1923 on six separate blocks, each block containing twelve treatments (plots). Plots (Fig. 1) were 10.1 m wide by 40.2 m long (0.04 ha in size) with a 2.2 m alley between plots. The blocks were 40.2 m wide by 145.3 m long (0.58 ha in size). The rotation and amendment treatments were suspended after the 1972 growing season. This study was located on the Columbus field of the Southeast Kansas Branch Experiment Station.

Soil amendment treatments were lime, barnyard manure, superphosphate, rock phosphate, and potash. A multiple year crop rotation scheme was superimposed and used on all plots.

Although there were 12 treatments and 6 blocks, due to treatment similarities and time required for sample analyses, only treatments 1, 3, 6, 10, and 12 of blocks 4, 5, and 6 were sampled for physical property analyses. Therefore, only details of those treatments and blocks will be presented in this thesis.

Treatment 1 received only lime. Applications of lime for all lime treated plots were just sufficient to produce a neutral reaction and were applied before alfalfa or sweet clover.

Treatment 3 received superphosphate and potash (KCl) in addition to the lime applications (similar to those in

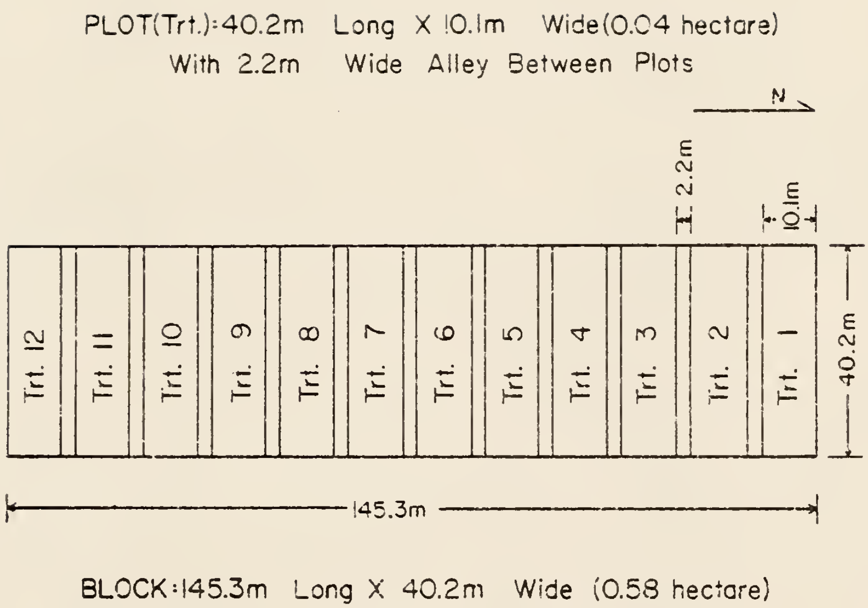

Fig. 1: Experimental plot design for the study. Each block has the same arrangement of treatments: blocks adjoin lengthwise.

treatment 1). The rate and method of superphosphate and potash fertilizer applications and the ratio of K_2O to P_2O_5 varied during the experiment (1923 through 1972).

Treatment 6 received lime as needed and barnyard manure at the rate of 18,160 kg/ha before seedling alfalfa and before plowing the flax stubble in preparation for wheat. Previous to 1930 the manure was applied before a corn crop.

Treatment 10 received the same lime and superphosphate as treatment 3 beginning in 1923. Potash (KCl) applications were initiated in 1962. Treatment 10 had no legume in the rotation. A grass mixture was substituted for alfalfa and sweet clover.

Treatment 12 received no chemical amendments or manure.

Soil Treatments and Amendments Status

There were changes in rates and methods of amendment material applications during the study (1923 through 1972). Fine ground limestone was originally applied at rates of 6,810 kg/ha to plots the first time they were seeded to alfalfa or sweet clover. Beginning in 1934, the limestone applications were 3,405 kg/ha before each seeding of alfalfa.

Table 1 shows the rate of lime application for blocks 4, 5, and 6 and the total lime rate (1923 through 1965) for each individual block (applied equally to treatments 1 through 11). All plots which have a lime application history have close to optimum soil pH (28). Lime applications were made at various times since 1923 to keep the soil pH near 6.8 (Table 1).

Barnyard manure was applied at a rate of 18,160 kg/ha

Table 1: History and rate of lime applied (kg/ha) to blocks 4, 5, and 6 (1923 through 1965). (Developed from Peterson (35).)

Year	Block 4	Block 5	Block 6
		kg/ha	
1923	-	6,810	6,810
1924	-	6,810	6,810
1925	-	-	6,810
1928	6,810	-	-
1933	2,270	-	-
1938	3,405	-	-
1954	-	6,810	-
Total	12,485	20,430	20,430

(Table 2). Manure was applied before seeding of first-year alfalfa and before corn during 1924-1930 in a five-year rotation. It was applied before two crops in each five-year rotation before 1954, and before two crops in each six-year rotation after 1954 (Table 2). Therefore, the rate of manure applied in the rotation was 36,320 kg/ha, which was probably too small to create any large increases in the soil organic matter content (28). Meyer and Whitney (28) reported that the manure applications increased the potasium levels slightly, and did not change the soil phosphorous levels appreciably. All manure was applied broadcast before planting and no report has been found of the manure composition. Table 3 includes the rate of

Table 2: Manure applied (kg/ha) to the crop in rotation (1923 through 1972). (Developed from Meyer and Beason (27).)

Crop	1923-1929	1930-1953	1954-1965	1966-1972
	-------	-------	kg/ha	-------
Alfalfa	18,160	18,160	18,160	-
Corn	18,160	-	-	18,160
Wheat	-	18,160	-	-
Soybean	-	-	18,160	18,160

Table 3: Amendment materials applied (kg/ha) (1923 through 1972). (Developed from Meyer and Beason (27).)

Amendment materials	Treatment no.	Block 4	Block 5	Block 6
		-------	kg/ha	-------
Lime	1,3,6,10	15,890	20,430	20,430
P_2O_5 as superphosphate	3,10	1,153	1,183	1,251
K_2O as KCl	3	1,336	1,410	1,388
K_2O as KCl (Beginning in 1962)	10	738	704	681
Manure	6	236,080	181,600	163,440

manure applied to treatment 6 in blocks 4, 5, and 6 since 1923.

Superphosphate was applied to the plots in different ways and quantities. Before 1930 it was broadcast at 56.8 kg/ha of 0-16-0 for corn and oats and 113.5 kg/ha of 0-16-0 for wheat before seeding. In 1930, superphosphate was drilled with the seed of wheat and oats.

Beginning in 1931, superphosphate was applied in a band when planting corn and soybeans. Also, in 1931, flax was added to the rotation and superphosphate (0-16-0) was drilled in the seed row at a rate of 113.5 kg/ha. In 1934, superphosphate was applied to the soybean seed row at a rate of 56.8 kg/ha of 0-16-0. The rate of superphosphate for flax was reduced in 1941 from 113.5 to 56.8 kg/ha of 0-16-0 and the rate for oats was increased from 56.8 to 113.5 kg/ha. Alfalfa received superphosphate annually at 170.3 kg/ha of 0-16-0 broadcast. Some years, superphosphate of a grade other than 0-16-0 was used, however, an equivalent amount of available phosphoric acid was supplied. Meyer and Whitney (28) found that the rate of phosphorus application was not adequate to bring the soil P amount to a desired level. Superphosphate was applied annually to the crops in rotation which remained for more than one year. Table 4 shows the amount of superphosphate (kg/ha P_2O_5) that was applied to the crop in rotation from 1923 through 1972.

Potash, before 1962, was applied only to treatment 3 in combination with superphosphate and lime in each block. Potash applications (applied as KCl but expressed here as K_2O) were

Table 4: Superphosphate (kg/ha P_2O_5) applied to the crop in rotation (1923 through 1972). (Developed from Meyer and Beason (27).)

Crops	Years										
	1923-1928	1929	1930	1931-1936	1937	1938-1940	1941-1946	1947	1948-1952	1953	1954-1972
	kg/ha										
Alfalfa	27	27	27	27	27	27	27	45	45	45	45
Redtop (trt. 10)	20	27	27	27	27	27	27	45	45	45	45
Corn	7	9	9	7	9	9	9	23	23	23	23
Wheat	14	18	18	14	18	18	18	34	34	34	34
Oats + sweetclover	7	9	9	7	9	15	18	34	34	34	
Flax			23	18	18	18	9	23	23		
Soybeans				7	9	9	9	23	23	23	23
Kafir (trt. 10)				7	9	9	9	23	23	23	
Grain sorghum											23
Bromegrass (trt. 10)											45

relatively low before 1947. Potash was applied on treatment 3 in proportion to available phosphoric acid anhydride (P_2O_5) as indicated by the following schedule for the various periods:

	P_2O_5:K_2O	
1924 through 1928	6:1	
1929 through 1946	3:1	
1947 through 1958	1:1	
1959 through 1972	1:1	on wheat
	2:1	on alfalfa
	3:1	on soybean and corn.

Starting in 1962, potash was applied to treatment 10. Meyer and Whitney (28) found that the potash application rates were not sufficient to build desirable soil potasium levels. Potash was applied annually to the crops in rotation which remained for more than one year. Beginning in 1930, potash was drilled in the row for small grains (was broadcast previously). Beginning in 1931, potash was applied when planting soybean and corn as a band application. In 1953, corn and soybean were changed to broadcast applications (also broadcast on grain sorghum in 1954). Table 5 shows the amount of potash (kg/ha K_2O) that was applied to the crop in rotation (1923 through 1972).

Crop Rotations

The crop rotation as initially planned consisted of: corn, oats plus sweetclover (wheat planted on treatment 10), sweetclover or cowpeas as green manure (by plowing down), wheat,

Table 5: Potash (kg/ha K_2O) applied to the crop in rotation (1923 through 1972). (Developed from Meyer and Beason (27).)

Crop	Years										
	1923-1928	1929	1930	1931-1936	1937	1938-1940	1941-1946	1947-1952	1953	1954-1958	1959-1972
	kg/ha										
Alfalfa	4.5	9	9	9	9	9	9	45	45	45	90
Redtop (trt. 10)	4.5	9	9	9	9	9	9	45	45		
Corn	1.1	3.4	3.3	2.3	3.4	3.4	3.4	23	23	23	23
Wheat	3.4	6	6	4.5	6	6	6	34	34	34	34
Oats + sweetclover	1.1	3.4	3.4	2.3	3.4	4.5	6	34	34		
Flax			6	6	6	6	3.4	23			
Soybeans				2.3	3.4	3.4	3.4	23	23	23	23
Kafir (trt. 10)				2.3	3.4	3.4	3.4	23	23		
Grain sorghum										23	68
Bromegrass (trt. 10)										46	90

wheat, and alfalfa (redtop planted on treatment 10). Cowpeas were used only when sweetclover failed. In either case, the green manure crop was plowed in the summer before wheat was seeded in the fall.

Alfalfa was not actually part of the continuous rotation until 1954. Before 1954, it was used as a "fill-in" for the rotation, being in a particular block depending on needs of the rotation. Alfalfa was always seeded on one of the six blocks and allowed to remain as long as it maintained a reasonably good stand, from three to five years. When alfalfa was plowed in the particular block, this block was incorporated in the five-year rotation, replacing one of the other blocks, which was removed from the five-year rotation and seeded to alfalfa.

The last of the six rotation blocks was seeded to alfalfa for the first time in the fall of 1945. This stand lasted through 1949, then one of the other blocks was replanted to alfalfa for a second time.

The rotation system was changed in the spring of 1931 to: corn, soybean for grain (kafir on treatment 10), flax, wheat, oats plus sweetclover as a spring green manure crop for corn (no sweetclover planted on treatment 10), and alfalfa (redtop on treatment 10).

This rotation was maintained until 1953. Flax was dropped from the cropping system that year because it had ceased to be of economic importance in Kansas.

In 1953 the rotation was changed to the following: corn, soybean (kafir on treatment 10), alfalfa (redtop on treatment

10), oats plus sweetclover (no sweetclover on treatment 10), sweetclover (second year for seed), and wheat.

The rotation was changed in 1954 to: corn, soybean (grain sorghum on treatment 10), wheat (fall planted after soybean), wheat, first year alfalfa (bromegrass on treatment 10) and second year alfalfa (bromegrass on treatment 10). The rotation and amendments were discontinued after 1972. Since 1973, 142 kg N/ha were applied annually to the plot area and grain sorghum yield determined.

Table 6 shows the total years of each individual crop in rotation (1923 through 1972).

Soil Type

Peterson (34) discussed that the soil is, for the most part, Cherokee silt loam (Cherokee series is a fine, mixed, thermic Typic Albaqualfs). The soil has a white ashy surface and a very dark-gray subsoil (silty clay starts about 38 cm depth). The subsoil is impervious to water and a drab color flecked with red, yellow, and gray. The field is nearly level with most of the surface drainage being toward the northwest. Landon (21) reported some spots approach a Bates sandy loam in the nature of the surface soil.

Table 6: Total years of each crop in rotation (1923 through 1972). (Taken from Meyer and Beason (27).)

Crop	Treatment no.	Block 4	Block 5	Block 6
		--- Number of years -----		
Corn	1,3,6,12	8	8	5
Oats + sweetclover	"	6	6	4
Cowpeas	"	1	1	-
Wheat	"	14	11	10
Kafir	"	-	-	1
Soybean	"	7	6	8
Flax	"	4	3	5
Alfalfa	"	9	13	15
Grain sorghum	"	-	-	1
Fallow	"	1	2	1
Corn	10	8	8	5
Oats	"	5	5	4
Wheat	"	15	12	10
Kafir	"	4	3	6
Flax	"	4	3	5
Redtop	"	5	8	10
Bromegrass	"	4	6	5
Grain sorghum	"	3	3	4
Fallow	"	2	2	1

MATERIAL AND METHODS

Soil Sampling

Disturbed and undisturbed soil samples were taken in September, 1976, from treatments 1, 3, 6, 10, and 12 in each of blocks 4, 5, and 6 (Fig. 1).

A double-cyclinder, hammer-driven core sampler was used to obtain the undisturbed soil samples. Soil cores were 7.6 cm in diameter and 7.6 cm tall and taken centered at soil depths of 5, 20, and 35 cm. Soil cores were stored until analyses in a refrigerator. Bulk density, penetrometer resistance, and soil water desorption curves were determined using the undisturbed soil core samples.

Disturbed soil samples were collected from the 1 to 9, 16 to 24, and 31 to 39 cm soil layers. They were placed in a greenhouse to air-dry and then stored under laboratory conditions until analyses were made. Particle size analysis, size distribution of water-stable aggregates, soil consistency limits, organic matter content, and soil compactibility were determined using the disturbed soil samples.

Soil Physical Properties Analyses

Organic matter content was determined using representative soil samples ground to pass through a 2-mm screen. The organic matter content (percent of dry weight) was determined by the Soil Testing Laboratory at Kansas State University using

spectrophotometer techniques.

Particle size analysis (using the hydrometer method) was conducted as described by Day (9). Soil was passed through a 2-mm sieve and a 40 g-sample taken for analysis. Sodium hexametaphosphate $(NaPO_3)_6$ was used as the dispersion agent (50 g of Na-hexametaphosphate/liter of distilled water). Soil samples were not treated with hydrogen peroxide because of low organic matter contents (28). The determinations were made in a constant temperature room (21°C).

The analysis of size distribution of water-stable aggregates was made on the surface soil (1 to 9 cm depth) using the wet-sieving technique described by Kemper and Chepil (19). Moistened soil samples were passed through an 8 mm sieve and only material between 4.76 mm and 8 mm were used in the analysis. Soil samples (25 g of the 4.76 to 8 mm material) were soaked 10 minutes on the upper screen (2.0 mm) of the sieve sets. The samples were wet-sieved at the rate of 38 strokes per minute (distance of 3.8 cm) for 10 minutes. Four sets of sieves with openings of 2.0, 1.0, 0.5, and 0.1 mm were used to retain the aggregates. The weight of aggregates on each sieve was determined by subtracting the weight of the sand and gravel from the weight of the oven-dry material retained after the wet-sieving. The analysis was repeated three times for each plot and the plot means are reported.

The soil consistency study included determination of the upper and lower plastic limits for the surface soil (1 to 9 cm layer) by the procedure of Sowers (42). Soil was ground in a

mortar with a rubber-covered pestle and then passed through a no. 40 sieve. The upper plastic limit was obtained from a flow curve constructed by plotting the water content versus the logarithm of number of blows using a mechanical upper plastic-limit device. The upper plastic limit (liquid limit) is the water content of the flow curve that corresponds to 25 blows. The lower plastic limit (plastic limit) was obtained by rolling out the soil on a glass plate with the fingers until the thread formed began to crumble when it reached a diameter of 3 mm. The plastic limit is the mean water content of three determinations. The plasticity number is the difference between the lower plastic limit and the upper plastic limit.

Water retained at various pressure potential values was determined using the undisturbed soil samples removed from each of 15 plots (3 depths per plot) by using a fritted-glass Buchner funnel apparatus. Pressure potential values of -5, -100, -225, and -450 cm of water were used. Soil water content by volume was determined at each of the four pressure potential values.

Penetrometer resistance measurements were made in the upper surface of the undisturbed soil samples (1, 16, and 31 cm depths). The penetrometer was equipped with a model PR005 proving ring with 0 to 22.7 kg (0 to 50 pounds) capacity, and a LC-2B dial indicator (0.5 cm range with brake) (manufactured by Soil Test Inc., 2205 Lee Street, Evanston, Ill., 60202). Proctor penetrometer needle, 0.65 cm^2 cross-section (Soil Test Model CN 419-2), was used to penetrate the soil surface for a distance of 0.6 cm.

A T-bar handle and a 45.7 cm shaft were fitted to Soil Test equipment to facilitate use. The penetrometer readings were taken immediately after removing the undisturbed samples from the fritted-glass Buchner funnels after equilibrium at -450 cm of water pressure potential. Six penetrometer measurements from each undisturbed sample were used in calculating the penetrometer resistance (the mean of six measurements is reported in bars).

The bulk density determinations were made using the core method procedure described by Blake (6). The undisturbed soil cores were placed in an oven at 105°C for 24 hours, and then weighed. The bulk density is determined by dividing the oven-dry mass by the soil volume.

The compaction studies for determining the optimum water content (g/g) for compaction and the maximum compaction under a given compactive effort were made according to the low compaction procedure for soil materials passing through a no. 4 sieve (ASTM 1958) described by Felt (13). A mold (10.2 cm in diameter and 11.6 cm high) and rammer (2.5 kg dropped from a height of 30.5 cm) were used to determine bulk density at six different soil water contents for each surface (1 to 9 cm) soil sample. The optimum water content for compaction and maximum compaction were found for each of the 15 field plots using a second power generated formula determined using values of bulk density and soil water content with computer regression analysis. Eighteen water content levels and 18 bulk density values (total from three blocks) were used in finding the generated formula for

each treatment. The analysis yielded the optimum water content for compaction, the maximum bulk density, the correlation coefficient (R), and the standard error ($S_{y \cdot x}$).

Statistical Analyses

The treatments were arranged in a geometric design rather than at random within each block. Also, the treatment sequence was identical in each of the six blocks. Analysis of variance was used in determining if there were significant differences between treatments and between blocks for each soil physical property in each of the three soil layers. Some soil physical properties were studied only from the surface layer, so that analyses of variance were carried out including only one layer. The statistical analyses were made regarding the experimental design as a split block design (24) rather than the actual strip block design, which has no correct analysis. Standard deviation of the mean were computed using Snedecor and Cochran (41) as reference.

RESULTS AND DISCUSSION

Organic Matter

Soil organic matter (O.M.) content for each of five treatment and three soil layers is presented in Table 7. An analysis of variance of O.M. data in each layer (depth considered an independent variable) indicated there were no significant differences at the 5% level in organic matter content between treatments (Table 7). An analysis of variance showed a significant decrease of O.M. content with depth at the 1% level.

Table 7: Organic matter content (percent of dry wt.) for five treatments in three depth layers. Values are means determined from three blocks.

Treatment number	Soil depth (cm) 1-9	16-24	31-39
	Organic matter (%)		
1	1.3	1.0	0.8
3	1.4	1.0	0.8
6	1.5	1.2	0.8
10	1.3	1.1	0.9
12	1.3	1.0	0.7
L.S.D. (0.05)	NS	NS	NS

Treatment 6 (lime-manure) and treatment 3 (lime-phosphate-potash, with legume) have higher, but not significant (5% level), organic matter contents than the other treatments in the surface layer (1 to 9 cm). Treatment 6 also had greater O.M. content than the other treatments in the 16 to 24 cm layer.

Manure was applied two times at a rate of 18,160 kg/ha during a six-year rotation (total of 36,320 kg/ha per six years). That was apparently not enough to create appreciable increases in organic matter content. Young et al. (50) reported that manure application at a rate of 18,160 kg/ha to corn in a four-year rotation increased the percentage of O.M. content from 7.1% (under check treatment) to 7.7% (in a livestock farm system). McIntosh and Varney(29) reported that annual applications of 44,000 kg/ha of fresh manure were needed for maintaining soil O.M. during the period of cultivation. Applications of manure less than that rate did not create any significant increase in organic matter content.

Particle Size Analysis

The clay, silt, and sand percentages for five treatments in three depth layers are given in Table 8. An analysis of variance of the percent clay, silt, and sand in each layer (depth was considered an independent variable) indicated no significant differences between treatments in clay and sand contents for all layers. There was a significant difference in silt content between treatments in the 1 to 9 and 16 to 24 cm

Table 8: Particle size analysis (% of dry wt.) for five treatments and three depth layers. Soil separate percentages are means determined from three blocks.

Treatment number	Soil depth (cm)	Material content (% by dry wt.)		
		Clay <0.002 mm	Silt 0.002-0.05 mm	Sand 0.05-2.0 mm
1	1-9	19.6	54.4	26.0
3	"	20.5	63.3	16.2
6	"	19.5	64.2	16.3
10	"	16.5	61.7	21.8
12	"	15.6	62.5	21.9
L.S.D. (0.05)		NS	6.2	NS
1	16-24	20.0	60.1	19.9
3	"	19.4	66.4	14.1
6	"	20.0	61.2	18.8
10	"	18.5	57.9	23.6
12	"	17.2	59.3	23.5
L.S.D. (0.05)		NS	5.1	NS
1	31-39	30.0	50.8	19.2
3	"	40.0	48.6	11.4
6	"	27.2	57.3	15.0
10	"	27.2	56.7	16.2
12	"	31.5	50.8	17.7
L.S.D. (0.05)		NS	NS	NS

layers at the 5% level.

Treatment 1 (lime) had greater variability between blocks in its sand and clay content than the others. That was possibly due to non-uniformity of surface texture in the field as Landon (21) pointed out. He found some areas that approached a Bates sandy loam in the nature of the surface soil. Table 8 shows that treatments 10 and 12 have lower clay content in the 1 to 9 and 16 to 24 cm layers. Also, treatment 1 has the highest percentage of sand and the lowest percentage of silt in the 1 to 9 cm layer.

Soil Bulk Density

Soil bulk density for five treatments and three soil depths is presented in Table 9. An analysis of variance of soil bulk density at each depth indicated there were no significant differences between treatments at the 5% level. Table 9 indicates the highest value of soil bulk density in the 1 to 9 cm layer was in treatment 12 (check).

An analysis of variance of bulk density values with depth showed a significant difference between depths at the 1% level. The soil bulk densities in the 1 to 9 and 31 to 39 cm soil layers. were less than those in the 16 to 24 cm layer for all treatments. The greater values of soil bulk density in the 1 to 9 cm layer were under treatments 12 and 6, and in the 31 to 39 cm layer were under treatments 6, 12, and 10.

Table 9: Soil bulk density (g/cm^3) for five treatments and three soil depths determined using undisturbed cores. The 7.6 cm tall cores were centered at the indicated depth. Values are means of three blocks.

Treatment number	Soil depth (cm)		
	5	20	35
	Soil bulk density (g/cm^3)		
1	1.38	1.44	1.37
3	1.37	1.54	1.39
6	1.40	1.53	1.44
10	1.38	1.51	1.41
12	1.43	1.50	1.42
L.S.D. (0.05)	NS	NS	NS

Penetrometer Resistance

Penetrometer resistance (bars) was determined for five treatments from three blocks at three soil depths. The measurements of penetrometer resistance were made after equilibration at -450 cm of water pressure potential. Penetrometer resistance data are presented in Table 10.

An analysis of variance of penetrometer resistance for each depth showed no significant difference (5% level) between treatments at the 1 and 31 cm depths. Penetrometer resistance was significantly different between treatments at the 16 cm depth (5% level). The smaller values of resistance to penetration were at the 1 cm depth for all treatments. Penetrometer resistance values for the 16 and 31 cm depths were similar for

Table 10: Penetrometer resistance (bars) for five treatments and three soil depths determined at -450 cm of water pressure potential. Values are means of three blocks.

Treatment number	Soil depth (cm)		
	1	16	31
	Penetrometer resistance (bars)		
1	6.8	12.5	12.4
3	10.1	15.0	14.8
6	9.6	21.4	16.0
10	9.3	14.5	15.5
12	7.5	14.8	13.9
L.S.D. (0.05)	NS	5.0	NS

all treatments.

An analysis of variance with depth showed a significant difference in penetrometer resistance between depths at the 1% level. Resistance at the 16 and 31 cm depths was not significantly different at the 5% level, but resistance at these depths was significantly greater than resistance at the 1 cm depth at the 5% level.

Water Retention

Water retained by soil is a function of soil texture (clay content), organic matter, and soil porosity. Increasing colloidal materials (clay and/or organic matter) causes an increase in the water retention of soils. This is due to the fact that the colloidal materials have a high surface area

(particularly important at low pressure potentials) and promote aggregation increasing total porosity (particularly important at high pressure potentials). Compacted soils have a greater amount of the intermediate pore sizes and water retained at intermediate pressure potentials than well-aggregated soils, because compaction decreases the between-aggregate pore size. At higher pressure potentials, the aggregated soils have greater water content than the compacted soils, because of greater total porosity. The amount of water by volume held by the soil at higher pressure potentials is an indication of porosity at the corresponding pressure potential.

Water content by volume (cm^3/cm^3) determined at four pressure potential values is illustrated in Table 11. These relationships were determined using undisturbed soil cores. An analysis of variance of the water content for each pressure potential value and each soil depth was conducted. In the 1 to 9 cm layer, a significant difference (5% level) was found between treatments only at -450 cm of water pressure potential. In the 16 to 24 cm layer a significant difference (5% level) was found between treatments only at -5 cm of water pressure potential. In the 31 to 39 cm layer, no significant differences were found between treatments.

An analysis of variance of water content at each value of pressure potential with depth a factor showed a significant difference (1% level) between depths for all values of pressure potential except -5 cm.

Treatment 6 had the lowest water content at -5 cm of water

Table 11: Water content by volume (cm^3/cm^3) determined at four pressure potentials. Values are means determined from three blocks. The 7.6 cm tall cores were centered at the indicated depth.

Treatment number	Soil depth (cm)	Pressure potential (-cm of water)			
		5	100	225	450
		----Water content by volume (cm^3/cm^3)---			
1	5	0.404	0.304	0.282	0.250
3	"	0.407	0.337	0.311	0.278
6	"	0.386	0.320	0.291	0.257
10	"	0.406	0.326	0.294	0.250
12	"	0.401	0.319	0.278	0.232
L.S.D. (0.05)		NS	NS	NS	0.024
1	20	0.422	0.373	0.346	0.310
3	"	0.398	0.363	0.344	0.324
6	"	0.396	0.358	0.337	0.313
10	"	0.397	0.355	0.332	0.302
12	"	0.391	0.337	0.311	0.277
L.S.D. (0.05)		0.019	NS	NS	NS
1	35	0.428	0.367	0.345	0.312
3	"	0.448	0.404	0.389	0.372
6	"	0.407	0.354	0.334	0.311
10	"	0.427	0.376	0.357	0.335
12	"	0.413	0.352	0.357	0.308
L.S.D. (0.05)		NS	NS	NS	NS

pressure potential in the surface sample (Table 11). In the 16 to 24 cm layer, treatment 1 had the highest value of water content at the first three pressure potentials. Treatment 3 had the highest water content at -450 cm of water pressure potential. Treatment 12 had the lowest water content value at all pressure potentials (16 to 24 cm depth). The sequence of treatments having the higher water content values at -450 cm of water pressure potential are:

1 to 9 cm layer	3>6>1 = 10>12.
16 to 24 cm layer	3>6>1>10>12.
31 to 39 cm layer	3>10>1>6>12.

Treatment 3 (lime-phosphate-potash, with legume) had the most water at -450 cm of water pressure potential while treatment 12 (check) had the least.

Size Distribution of Water-Stable Aggregates

Size distribution of water-stable aggregates (aggregate mass from a 25 g soil sample) for the five treatments using 2, 1, 0.5, and 0.1 mm size sieves is shown in Table 12. An analysis of variance for the size distrubution of aggregates showed no significant difference (5% level) between treatments for all size ranges except the 1 to 2 mm size.

Treatments 3, 1, and 6 have greater macroaggregates (aggregates greater than 1 mm size) than treatments 12 and 10. The sequence of treatments having greater amounts of macroaggregates (8 mm>Agg.>1 mm) is: 3>1>6>12>10. The sequence of treatments having greater microaggregates (1.0 mm>Agg.>0.1

Table 12: Size distribution of water-stable aggregates in the 1 to 9 cm layer of the five treatments. Values are means determined from three blocks. Values are the aggregate mass (g) from a 25 g soil sample.

Treatment number	<8 mm Agg. >2 mm	<2 mm Agg. >1 mm	<1 mm Agg. >0.5 mm	<0.5 mm Agg. >0.1 mm	<8 mm Agg. >0.1 mm
	---------------- Aggregate mass (g) -------------				
1	1.6	1.3	1.7	3.5	8.1
3	1.6	1.4	2.0	4.9	10.0
6	0.9	1.1	2.3	6.1	10.3
10	0.6	0.5	1.2	5.0	7.3
12	1.0	0.6	1.1	3.3	5.9
L.S.D. (0.05)	NS	0.6	NS	NS	NS

mm) is: 6>3>10>1>12. The sequence of treatments having greater total aggregate mass (8mm>Agg.>0.1mm) is: 6>3>1>10>12. Treatment 10 (lime-superphosphate-potash, with no legume) had the least amount of macroaggregates. Comparing treatment 10 with treatment 3 (lime-superphosphate-potash, with legume in rotation), indicates an apparent benefit from legume in promoting macroaggregates. The data indicate that manure (treatment 6) was effective in increasing soil microaggregates mass.

Consistency Limits

Soil consistency varies with many factors such as soil texture, organic matter, structure, clay content and type of clay, type of cations in soil, and water content. Water plays an important role in soil consistency in a particular field

environment because of its variability during the short-term.

The consistency limits (UPL, LPL, and PN) for the surface soil layer are given in Table 13. An analysis of variance of upper plastic limit data showed a significant difference between treatments at the 5% level. Treatments 6 and 3 had significantly higher values of UPL than treatments 10 and 12. These differences in UPL are possibly due to differences in organic matter content (Table 7). Treatment 12 had the lowest values of UPL and PN. This is possibly because treatment 12 had the lowest clay content in the surface layer (Table 8). The difference in PN between treatments was significant at the 5%

Table 13: The upper plastic limit (UPL), lower Plastic limit (LPL), and plasticity number (PN) for the surface layer (1 to 9 cm) of the five treatments. Values are means of three blocks.

Treatment number	Consistency limits		
	UPL	LPL	PN
1	27	15	12
3	28	16	12
6	28	16	12
10	26	15	11
12	25	16	9
L.S.D. (0.05)	1.7	NS	1.3

level. No significant difference existed between the PN in amendment treatments (1, 3, 6, and 10) at the 5% level, but all amendment treatments had significantly greater values of PN than treatment 12 (check).

Soil Compactibility

Soil compaction can have adverse effects upon plant growth by increasing the mechanical impedance and altering the extent and configuration of the pore space. Soil compactibility is affected by many factors such as compactive effort (load applied), water content, organic matter content, and clay content. The bulk density to which a given soil can be compacted under a specific load varies with the soil water content. The amount of water at which soil has a maximum bulk density is called the optimum water content for compaction. It varies with clay content and organic matter content. Clay and/or organic matter content increase causes a lower maximum compaction and an increased optimum water content for compaction. Applying a constant compactive effort and varying the water content, yields different compactibility curves for soils differing in clay or O.M. content.

A study of the degree of compaction under a specific load at various water contents was made using surface soil samples (1 to 9 cm) from the five treatments. Figure 2 illustrates the influence of different treatments on maximum compactibility of the soil and the optimum water content for compaction.

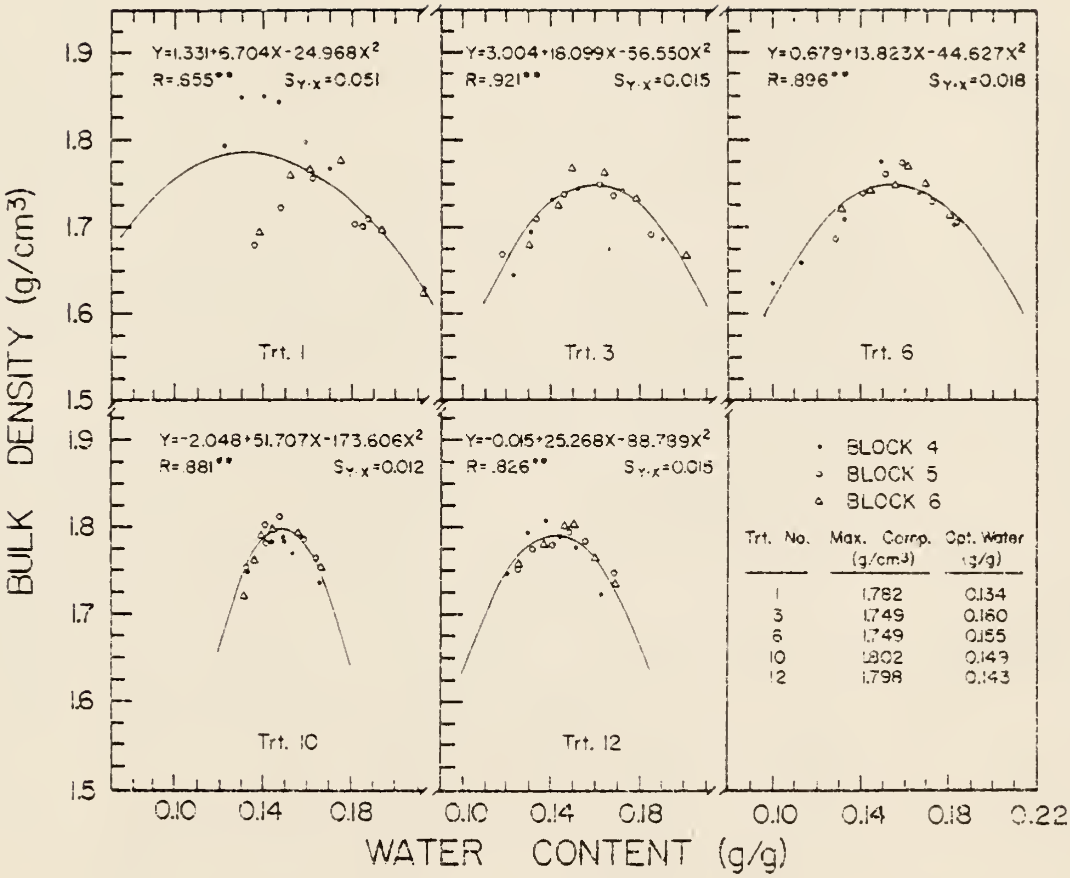

Fig. 2: Soil compactibility curves for the surface layer (1 to 9 cm) of the five treatments.

Treatments 3 and 6 had lower maximum compaction and higher optimum water content for compaction than the others. These results are likely due to having slightly higher organic matter and clay contents in the surface (Tables 7 & 8).

Treatment 1 was repeated due to wide variations in data between blocks. The second set of data showed the same pattern as the original data. The variation of data in treatment 1 was possibly due to variations in particle size distribution in the surface layer. Block 4 had more sand (36%) and less clay (14%) which would likely produce a higher maximum bulk density and a lower optimum water content for compaction compared to blocks 5 and 6 (treatment 1, Figure 2).

An analysis of variance showed no significant difference between treatments in the maximum compaction values at the 5% level (Table 14). The optimum water content for compaction had significant difference between treatments at the 5% level.

Grain Sorghum Yield

Grain sorghum yields were taken for years between final rotation and fertilizer applications (January 1973) and the collection of soil samples (September 1976). The yield data are presented in Table 15. Since January 1973, 142 kgN/ha was applied annually to all plots. Analysis of variance of the yield data within each year and for the four-year mean indicate significant differences between treatments at the 5% level for all years and the four-year mean. The check treatment during the 50-year program (treatment 12) has produced the lowest four-year mean yield following discontinuance of the

Table 14: Maximum compaction (g/cm^3) and optimum water content (g/g) for compaction for the surface layer (1 to 9 cm) of the five treatments. Values were obtained by using data from three blocks for each treatment in the regression analysis.

Treatment number	Maximum compaction (g/cm^3)	Optimum water content (g/g)
1	1.782	0.134
3	1.749	0.160
6	1.749	0.155
10	1.802	0.149
12	1.798	0.143
L.S.D. (0.05)	NS	0.011

Table 15: Grain sorghum yield (bu/acre) during 1973 through 1976. Yields are reported at 12.5% moisture content.

Treatment number	Year 1973	1974	1975	1976	Four-year mean
	Grain yield (bu/acre)				
1	61.6	37.7	33.6	98.9	58.0
3	77.4	66.0	50.8	135.9	82.5
6	96.3	64.6	39.7	130.3	82.7
10	72.0	66.2	60.3	143.1	85.4
12	59.0	37.6	35.1	63.4	48.8
L.S.D. (0.05)	20.0	16.9	9.1	8.9	20.7

amendments-rotation study. Treatment 1 (lime) has had the next lowest four-year mean grain sorghum yield. Treatments 3, 6, and 10 have a very similar four-year mean grain yield and are all significantly greater (5% level) than the four-year mean yield of treatments 1 and 12.

The sequence of treatments having greater grain sorghum yield is as follows:

Year	Sequence
1973	6>3>10>1>12
1974	10>3>6>1>12
1975	10>3>6>12>1
1976	10>3>6>1>12
Four-year mean	10>6>3>1>12

An assessment of whether the increased yields in treatments 10, 6, and 3 as compared to 1 and 12 are due to physical or chemical (nutrients) reasons is difficult to make without a thorough chemical evaluation of the soil. In a study of the same treatments, Meyer and Whitney (28) found increases in the pH values due to lime applications. They also determined the amount of available phosphorus and exchangable K for all treatments to see the effects of the amendment materials on the residual P and K in the 0 to 15 and 15 to 30 cm layers (Table 16). As indicated in Table 16 treatments 3 and 10 had applications of lime, phosphate, and potash and treatment 6 had applications of lime and manure. Therefore, it is likely that residual materials are available for plant use in those plots.

Table 16: Soil pH, available phosphorous (kg/ha), and exchangable potassium (kg/ha) in the 0 to 15 and 15 to 30 cm soil layers of the five treatments studied. Values are the mean from three blocks. (Developed from Meyer and Whitney (28).)+

Treatment	0-15 cm soil layer			15-30 cm soil layer		
	pH	Avail. P (kg/ha)	Exch. K (kg/ha)	pH	Avail. P (kg/ha)	Exch. K (kg/ha)
L (no. 1)	6.2	6.7	202.0	5.9	7.3	185.7
L, P, K (no. 3)	6.1	21.3	253.3	6.0	15.3	183.3
L, M (no. 6)	6.2	11.3	221.7	6.0	8.7	166.7
L, P, K (no legume) (no. 10)	6.5	54.7	245.3	6.5	28.3	168.3
Check (no. 12)	5.4	9.7	162.3	5.6	7.7	147.3
L.S.D. (0.05)	0.18	10.1	35.2	0.41	4.4	NS

L = lime, P = superphosphate, K = potash, and M = manure.

+ Soil samples were taken in the spring of 1973.

Treatments 1 (lime) and 12 (check) would likely have a lower nutrient level. The significant differences shown in Table 16 may be the reasons for the significant differences between treatments in grain sorghum yield (Table 15). No consistent or overwhelming advantage in physical properties of treatments 3, 6, and 10 over physical properties in treatments 1 and 12 could be determined from these thesis data. Comparing these thesis data and the chemical data of Meyer and Whitney (28) it appears the 50 years of soil amendments may have had more influence on subsequent grain sorghum yields because of residual nutrients and soil pH than because of alterations of the physical properties.

SUMMARY AND CONCLUSION

A study of the influence of soil amendments on physical properties of Cherokee silt loam was initiated in 1923. A crop rotation scheme was superimposed over the treatments. Statistical analyses were carried out using techniques for a split block design although the treatments were not randomized within each block. Analyses of variance were conducted to evaluate if any significant differences existed within soil physical properties created by the various treatments.

An analysis of variance was determined for each physical property and for each soil layer (depth being an independent variable). The analysis of variance showed no significant difference (5% level) in organic matter content or in soil bulk density of the soil depths analyzed from the five treatments. A significant difference in penetrometer resistance of the treatments did exist at the 16 cm depth (5% level). The analysis of variance of soil separates revealed that only the silt content in the 1 to 9 and 16 to 24 cm layers was significantly different between treatments at the 5% level. The analysis of variance for the water content at various pressure potentials revealed that only the water content at -5 cm of water pressure potential in the 16 to 24 cm layer and at -450 cm of water pressure potential in the 1 to 9 cm layer had significant differences among treatments at the 5% level.

The analyses of variance for the physical properties

studied from the surface 1 to 9 cm layer only (consistency limits, size distribution of water-stable aggregates, and soil compactibility) revealed the following:

a. No significant difference (5% level) between treatments in size of water-stable aggregates except for the 1 to 2 mm size aggregates.

b. The upper plastic limit and plasticity number were significantly different between treatments at the 5% level.

c. At the 5% level there was a significant difference between treatments in the optimum water content for compaction, but there was not a significant difference between maximum compaction values.

Treatments 6 (lime-manure) and 3 (lime-superphosphate-potash, with legume in rotation) had slightly greater organic matter content than treatment 10 (lime-superphosphate-potash, with no legume in rotation), 12 (check), and 1 (lime). The organic matter content decreased with depth for all treatments. Bulk density values were greater for all treatments in the 16 to 24 cm layer. The greater values of soil bulk density in the 1 to 9 cm layer were under treatments 12 and 6, and in the 31 to 39 cm layer were under treatments 6, 12, and 10. Penetrometer resistance was similar at the 16 and 31 cm depths and lowest at the 1 cm depth. The sequence of amount of aggregates for treatments are:

Macroaggregates (8mm>Agg.>1mm) : 3>1>6>12>10.

Microaggregates (1mm>Agg.>0.1mm) : 6>3>10>1>12.

Total aggregates (8mm>Agg.>0.1mm) : 6>3>1>10>12.

Treatments 3 and 6 had the higher values of UPL and LPL. This is probably because they have the greatest amount of O.M. in the 1 to 9 cm layer. Treatments 3 and 6 had lower maximum compaction and greater optimum water content for compaction than the other treatments. This is also likely due to their having greater O.M. content.

Grain sorghum was planted after discontinuing the amendment applications to evaluate the residual effects of the amendments on crop yield. Analysis of variance showed significant differences in yield between treatments at the 5% level during each of the years 1973-1976 as well as for the four-year mean. Treatments 10, 6, and 3 had the largest grain yield. They were significantly higher in grain sorghum yield than treatments 1 and 12. Treatment 12 (check) had the lowest four-year yield of the five treatments. Therefore, the amendments caused increased grain sorghum yield either chemically by supplying additional residual nutrients or physically by improving the physical conditions. It appears the amendment materials had more influence upon yield production through chemical than through physical processes.

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APPENDIX

Table 1A: Organic matter content (% of dry wt.) for five treatments in three depth layers.

Treatment number	1-9 cm layer					16-24 cm layer					31-39 cm layer				
	Block no.			$\overline{X}$	$S_{\overline{x}}$	Block no.			$\overline{X}$	$S_{\overline{x}}$	Block no.			$\overline{X}$	$S_{\overline{x}}$
	4	5	6			4	5	6			4	5	6		
	Organic matter content (%)														
1	1.3	1.6	1.0	1.3	0.17	0.9	1.2	0.9	1.0	0.10	0.6	0.7	1.1	0.8	0.15
3	1.2	1.5	1.6	1.4	0.12	1.1	1.0	1.0	1.0	0.03	0.4	0.8	1.3	0.8	0.26
6	1.2	1.6	1.6	1.5	0.13	1.0	1.2	1.4	1.2	0.12	0.5	1.0	1.0	0.8	0.17
10	1.0	1.5	1.5	1.3	0.17	0.9	1.3	1.1	1.1	0.12	0.9	1.0	0.8	0.9	0.07
12	1.5	1.4	1.0	1.3	0.15	1.3	0.8	0.9	1.0	0.15	1.1	0.6	0.5	0.7	0.19

Table 2A: Percent of clay, silt, and sand for five treatments and three depth layers.

Table 2A: Percent of clay, silt, and sand for five treatments and three depth layers.

Treat. no.	Block no.	1-9 cm layer Clay	1-9 cm layer Silt	1-9 cm layer Sand	16-24 cm layer Clay	16-24 cm layer Silt	16-24 cm layer Sand	31-39 cm layer Clay	31-39 cm layer Silt	31-39 cm layer Sand
		% by weight								
1	4	14.4	49.6	36.0	13.0	57.0	30.0	13.0	56.5	30.5
	5	18.3	58.7	23.0	18.0	65.2	16.8	19.0	60.0	21.0
	6	26.0	54.8	19.2	29.0	58.0	13.0	58.0	36.0	6.0
	$\bar{X}$	19.6	54.4	26.1	20.0	60.1	19.9	30.0	50.8	19.2
	$S_{\bar{x}}$	3.41	2.64	5.09	4.73	2.58	5.15	14.11	7.49	7.13
3	4	19.5	66.1	14.4	18.0	65.0	17.0	21.6	62.8	15.6
	5	18.5	59.1	22.4	18.3	68.3	13.4	42.0	44.5	13.5
	6	23.5	64.7	11.8	22.0	66.0	12.0	56.5	38.5	5.0
	$\bar{X}$	20.5	63.3	16.2	19.4	66.4	14.1	40.0	48.6	11.4
	$S_{\bar{x}}$	1.53	2.14	3.19	1.29	0.98	1.49	10.12	7.31	3.24
6	4	19.0	64.0	17.0	21.0	57.3	21.7	29.0	52.5	18.5
	5	18.5	63.5	18.0	18.0	67.5	14.5	23.5	59.5	17.0
	6	21.0	65.0	14.0	21.0	58.7	20.3	29.0	60.0	11.0
	$\bar{X}$	19.5	64.2	16.3	20.0	61.2	18.8	27.2	57.3	15.5
	$S_{\bar{x}}$	0.76	0.44	1.20	1.0	3.19	2.20	1.83	2.42	2.29
10	4	15.5	63.3	21.2	15.5	60.0	24.5	21.0	60.0	19.0
	5	15.6	58.8	25.6	18.4	57.0	24.6	26.0	56.5	17.5
	6	18.5	63.0	18.5	21.6	56.7	21.7	34.5	53.5	16.2
	$\bar{X}$	16.5	61.7	21.8	18.5	57.9	23.6	27.2	56.7	16.2
	$S_{\bar{x}}$	0.98	1.45	2.07	1.76	1.05	0.95	3.94	1.88	2.13
12	4	15.6	61.6	22.8	18.0	57.0	25.0	34.5	50.5	15.0
	5	15.7	59.3	25.0	15.5	64.0	20.5	26.0	56.0	18.0
	6	15.5	66.5	18.0	18.0	57.0	25.0	34.0	46.0	20.0
	$\bar{X}$	15.6	62.5	21.9	17.2	59.3	23.5	31.5	50.8	17.7
	$S_{\bar{x}}$	0.06	2.12	2.07	0.83	2.33	1.50	2.75	2.89	1.45

Table 3A: Soil bulk density (g/cm^3) for five treatments and three depth layers determined using undisturbed soil cores. The 7.6 cm tall cores were centered at the indicated depth.

Treatment no.	5 cm depth					20 cm depth					35 cm depth				
	Block no.					Block no.					Block no.				
	4	5	6	$\bar{X}$	$S_{\bar{x}}$	4	5	6	$\bar{X}$	$S_{\bar{x}}$	4	5	6	$\bar{X}$	$S_{\bar{x}}$
	Soil bulk density (g/cm^3)														
1	1.44	1.34	1.37	1.38	0.03	1.43	1.44	1.44	1.44	0.01	1.44	1.30	1.38	1.37	0.04
3	1.33	1.35	1.44	1.37	0.03	1.62	1.51	1.48	1.54	0.04	1.50	1.37	1.31	1.39	0.06
6	1.41	1.38	1.41	1.40	0.01	1.54	1.59	1.53	1.55	0.02	1.45	1.47	1.41	1.44	0.02
10	1.39	1.37	1.37	1.38	0.01	1.56	1.57	1.51	1.55	0.02	1.44	1.40	1.40	1.41	0.01
12	1.42	1.37	1.51	1.43	0.04	1.44	1.53	1.50	1.49	0.03	1.37	1.46	1.43	1.42	0.03

Table 4A: Penetrometer resistance (bars) from six spots for each soil core of the five treatments (3 blocks by 3 depths).

Treat. no.	Block no.	Soil depth (cm)	Penetrometer resistance (bars)+						$\bar{X}$	$S_{\bar{x}}$
			1	2	3	4	5	6		
1	4	1	6.43	6.13	7.56	7.62	7.32	7.32	7.06	0.26
		16	14.22	13.92	14.10	14.22	14.10	14.45	14.17	0.07
		31	13.32	12.73	12.13	13.32	13.09	13.32	12.99	0.20
	5	1	7.62	7.32	6.73	7.80	7.44	6.90	7.30	0.17
		16	11.30	10.95	12.08	12.37	13.26	12.49	12.08	0.34
		31	10.83	10.29	12.43	13.92	11.54	13.62	12.11	0.60
	6	1	6.19	5.95	6.07	5.48	6.19	6.67	6.09	0.16
		16	10.95	11.24	10.95	10.95	12.13	11.24	11.24	0.19
		31	11.66	11.42	11.90	12.37	12.13	11.96	11.91	0.14
3	4	1	10.65	9.16	10.00	10.29	10.95	10.35	10.23	0.25
		16	19.86	18.02	20.75	19.86	20.10	20.75	19.89	0.41
		31	18.20	19.27	19.56	16.89	20.99	16.89	18.63	0.66
	5	1	9.10	8.57	9.16	9.76	8.81	8.93	9.06	0.17
		16	13.62	13.03	14.22	13.33	13.62	13.33	13.53	0.17
		31	13.92	13.62	13.62	14.16	14.22	13.62	13.86	0.12
	6	1	10.95	10.95	10.95	11.07	11.25	11.49	11.11	0.09
		16	11.84	12.13	11.24	11.54	11.84	11.24	11.64	0.15
		31	12.43	11.79	11.54	11.96	11.72	11.84	11.88	0.12

Table 4A: (Continued)

Treat. no.	Block no.	Soil depth (cm)	Penetrometer resistance (bars)+ 1	2	3	4	5	6	$\bar{X}$	$S_{\bar{x}}$
6	4	1	10.05	10.11	9.46	9.16	10.35	9.46	9.77	0.19
		16	20.75	20.93	21.64	21.05	22.54	21.94	21.48	0.28
		31	16.30	15.82	16.30	15.40	15.58	15.70	15.85	0.15
	5	1	10.59	10.05	10.32	10.05	9.81	10.77	10.27	0.15
		16	27.29	28.06	26.40	27.05	26.10	26.16	26.84	0.31
		31	17.48	16.89	18.38	18.08	16.89	18.38	17.68	0.29
	6	1	7.68	9.76	7.97	9.16	9.36	7.68	8.60	0.38
		16	16.89	16.89	14.51	16.00	15.52	15.70	15.92	0.37
		31	14.22	13.03	14.39	14.81	14.51	14.99	14.33	0.28
10	4	1	8.87	9.46	8.87	8.57	8.57	8.87	8.87	0.13
		16	14.81	14.22	15.11	13.92	15.70	15.70	14.91	0.30
		31	18.38	18.26	18.08	18.68	19.27	18.38	18.51	0.17
	5	1	10.05	9.16	8.57	7.97	10.05	10.35	9.36	0.39
		16	15.11	15.70	14.81	16.30	16.89	15.70	15.75	0.31
		31	14.51	14.51	14.31	14.11	13.62	13.32	14.06	0.12
	6	1	10.35	9.76	9.46	10.05	9.46	9.22	9.72	0.17
		16	12.43	12.73	12.43	13.02	13.32	13.32	12.88	0.17
		31	13.92	13.62	13.62	14.51	14.51	13.62	13.97	0.18

Table 4A: (Continued)

Table 4A: (Continued)

Treat. no.	Block no.	Soil depth (cm)	Penetrometer resistance (bars)+						$\bar{X}$	$S_{\bar{x}}$
			1	2	3	4	5	6		
12	4	1	4.88	4.41	4.71	4.41	4.59	4.47	4.58	0.08
		16	14.81	17.19	15.70	14.22	16.00	14.51	15.41	0.45
		31	15.40	14.81	16.00	15.29	15.11	15.11	15.29	0.16
	5	1	9.04	8.87	8.81	9.10	8.69	8.57	8.85	0.08
		16	14.75	14.87	13.92	16.00	16.24	16.83	15.44	0.45
		31	14.51	14.27	16.00	14.04	15.52	15.70	15.01	0.34
	6	1	8.57	9.16	7.97	10.35	10.35	8.45	9.14	0.41
		16	12.73	12.13	13.92	14.39	13.62	14.22	13.50	0.36
		31	11.25	11.54	10.95	11.25	11.84	11.25	11.35	0.13

+All values were obtained from the first power regression equation:

$$Y = 2.625 + 0.023\ X$$

where Y = penetrometer resistance (bars)

X = proving ring deflection (cm x 10^4)

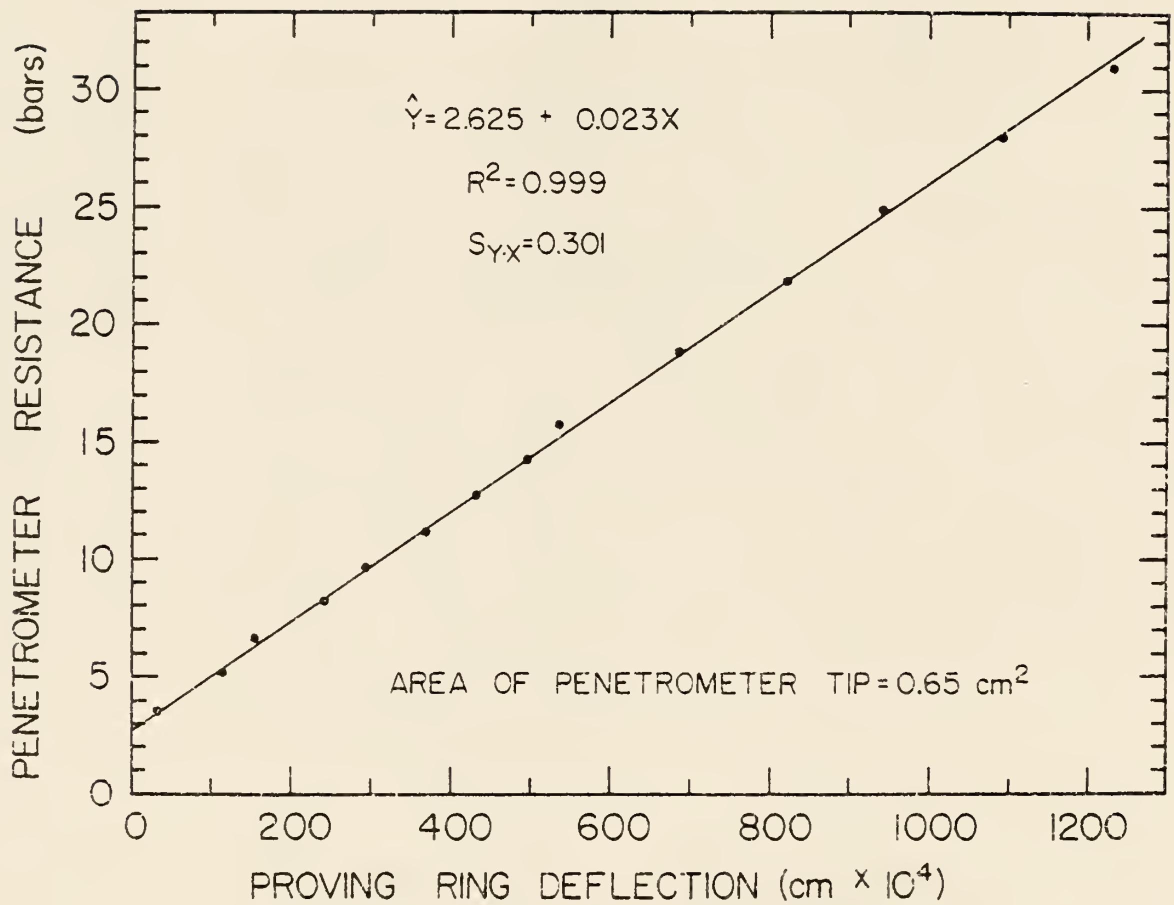

Fig. 1A: Penetrometer resistance (bars) versus proving ring deflection (cm x 10^4).

Table 5A: Water content by volume (cm^3/cm^3) at four pressure potential values for five treatments and three depth layers.

Treatment no.	Pressure potential (-cm H_2O)	1-9 cm layer				
		Block 4	Block 5	Block 6	$\bar{X}$	$S_{\bar{x}}$
		---- Water content (cm^3/cm^3) -----				
1	5	0.385	0.413	0.415	0.404	0.010
	100	0.287	0.317	0.322	0.304	0.011
	225	0.259	0.291	0.296	0.282	0.012
	450	0.225	0.260	0.266	0.250	0.013
3	5	0.410	0.414	0.397	0.407	0.005
	100	0.331	0.337	0.342	0.337	0.003
	225	0.305	0.308	0.321	0.311	0.005
	450	0.271	0.273	0.290	0.278	0.006
6	5	0.395	0.395	0.369	0.386	0.009
	100	0.327	0.329	0.302	0.320	0.009
	225	0.297	0.300	0.278	0.291	0.007
	450	0.262	0.263	0.247	0.257	0.005
10	5	0.401	0.400	0.418	0.406	0.006
	100	0.328	0.320	0.331	0.326	0.003
	225	0.291	0.289	0.301	0.294	0.004
	450	0.242	0.245	0.264	0.250	0.007
12	5	0.405	0.411	0.388	0.401	0.007
	100	0.317	0.313	0.327	0.319	0.004
	225	0.272	0.270	0.292	0.278	0.007
	450	0.221	0.223	0.252	0.232	0.010

Table 5A: (Continued)

Treatment no.	Pressure potential (-cm H_2O)	16-24 cm layer				
		Block 4	Block 5	Block 6	$\bar{X}$	$S_{\bar{x}}$
		---- Water content (cm^3/cm^3) -----				
1	5	0.406	0.413	0.447	0.422	0.013
	100	0.332	0.353	0.433	0.373	0.031
	225	0.293	0.328	0.416	0.346	0.037
	450	0.235	0.298	0.397	0.310	0.047
3	5	0.383	0.399	0.411	0.398	0.008
	100	0.355	0.356	0.377	0.363	0.007
	225	0.338	0.335	0.359	0.344	0.008
	450	0.319	0.311	0.341	0.324	0.009
6	5	0.396	0.392	0.399	0.396	0.002
	100	0.354	0.358	0.360	0.358	0.002
	225	0.333	0.339	0.340	0.337	0.002
	450	0.305	0.316	0.319	0.313	0.004
10	5	0.397	0.385	0.408	0.397	0.007
	100	0.356	0.353	0.358	0.355	0.002
	225	0.330	0.333	0.333	0.332	0.001
	450	0.293	0.307	0.304	0.302	0.004
12	5	0.393	0.386	0.393	0.391	0.004
	100	0.338	0.340	0.332	0.337	0.002
	255	0.311	0.314	0.308	0.311	0.002
	450	0.274	0.280	0.277	0.277	0.002

Table 5A: (Continued)

Treatment no.	Pressure potential (-cm H_2O)	31-39 cm layer				
		Block 4	Block 5	Block 6	$\bar{X}$	$S_{\bar{x}}$
		---- Water content (cm^3/cm^3) -----				
1	5	0.385	0.414	0.485	0.428	0.030
	100	0.316	0.331	0.454	0.367	0.044
	225	0.282	0.306	0.422	0.345	0.050
	450	0.230	0.278	0.429	0.312	0.060
3	5	0.390	0.466	0.487	0.448	0.029
	100	0.342	0.429	0.441	0.404	0.031
	225	0.324	0.415	0.428	0.389	0.033
	450	0.300	0.401	0.416	0.372	0.036
6	5	0.406	0.395	0.417	0.407	0.006
	100	0.349	0.342	0.371	0.354	0.009
	225	0.329	0.318	0.355	0.334	0.001
	450	0.307	0.289	0.336	0.311	0.014
10	5	0.399	0.419	0.464	0.427	0.019
	100	0.349	0.355	0.425	0.376	0.024
	225	0.329	0.332	0.411	0.357	0.027
	450	0.303	0.307	0.394	0.335	0.030
12	5	0.430	0.395	0.414	0.413	0.010
	100	0.372	0.334	0.351	0.352	0.011
	225	0.354	0.311	0.328	0.331	0.013
	450	0.355	0.284	0.304	0.308	0.015

Table 6A: Size distribution of aggregates (aggregate mass/25 grams of oven dry soil sample) for five treatments for the 1 to 9 cm layer. The values are mean of three determinations on the oven dry basis.

Treatment no.	Block no.	<8 mm Agg. >2 mm	<2 mm Agg. >1 mm	<1 mm Agg. >0.5 mm	<0.5 mm Agg. >0.1 mm	<8 mm Agg. >0.1 mm
		g/25 g sample				
	4	0.7	0.6	0.5	2.6	4.4
	5	2.2	1.5	2.0	4.2	9.9
1	6	2.1	1.7	2.6	3.7	10.1
	$\bar{X}$	1.6	1.3	1.7	3.5	8.1
	$S_{\bar{x}}$	0.48	0.36	0.63	0.48	1.90
	4	1.0	1.1	1.5	5.6	9.2
	5	1.9	1.4	1.5	4.1	8.9
3	6	2.0	1.7	3.1	5.1	11.9
	$\bar{X}$	1.6	1.4	2.0	4.9	10.0
	$S_{\bar{x}}$	0.32	0.18	0.51	0.45	0.95
	4	0.5	0.8	2.2	5.1	8.6
	5	1.3	1.2	0.9	5.7	9.1
6	6	1.0	1.3	3.6	7.4	13.3
	$\bar{X}$	0.9	1.1	2.3	6.1	10.4
	$S_{\bar{x}}$	.0.29	0.17	0.79	0.69	1.51
	4	0.8	0.6	1.0	4.3	6.7
	5	0.7	0.4	1.3	4.4	6.8
10	6	0.4	0.4	1.2	6.3	8.3
	$\bar{X}$	0.6	0.5	1.2	5.0	7.3
	$S_{\bar{x}}$	0.14	0.07	0.09	0.65	0.52
	4	0.4	0.5	1.4	5.2	7.5
	5	0.7	0.3	0.6	1.7	3.3
12	6	1.9	0.8	1.2	2.9	6.8
	$\bar{X}$	1.0	0.6	1.1	3.3	5.9
	$S_{\bar{x}}$	0.45	0.19	0.25	1.02	1.29

Table 7A: The upper plastic limit (UPL), lower plastic limit (LPL), and plasticity number (PN) for the surface layer (1 to 9 cm) of the five treatments.

Treatment no.	Consistency limit	Block 4	Block 5	Block 6	$\bar{X}$	$S_{\bar{x}}$
1	UPL	25.2	27.4	28.1	26.9	0.86
3	"	28.3	27.3	27.7	27.8	0.29
6	"	27.5	27.5	28.5	27.8	0.34
10	"	26.9	26.4	25.5	26.3	0.42
12	"	24.8	24.6	25.3	24.9	0.21
1	LPL	14.8	15.1	15.4	15.1	0.19
3	"	16.4	15.0	16.6	16.0	0.51
6	"	15.1	15.7	15.7	15.5	0.20
10	"	15.7	15.5	14.4	15.2	0.42
12	"	15.5	15.2	16.5	15.7	0.38
1	PN	10.4	12.3	12.6	11.8	0.69
3	"	11.8	12.2	11.1	11.7	0.32
6	"	12.3	11.8	12.8	12.3	0.26
10	"	11.3	10.8	11.1	11.1	0.15
12	"	9.2	9.4	8.8	9.2	0.17

Table 8A: Bulk density (g/cm^3) and water content for compactibility analysis of the surface layer (1 to 9 cm) of the five treatments.

Treat. no.	Block 4		Block 5		Block 6	
	Water content (g/g)	Bulk density (g/cm^3)	Water content (g/g)	Bulk density (g/cm^3)	Water content (g/g)	Bulk density (g/cm^3)
	0.122	1.793	0.136	1.679	0.138	1.694
	0.130	1.849	0.148	1.722	0.152	1.760
1	0.140	1.850	0.162	1.756	0.161	1.760
	0.147	1.844	0.182	1.704	0.175	1.775
	0.159	1.798	0.185	1.701	0.193	1.697
	0.170	1.767	0.188	1.709	0.213	1.626
	0.123	1.648	0.118	1.670	0.130	1.682
	0.131	1.698	0.134	1.723	0.144	1.728
3	0.141	1.735	0.146	1.739	0.150	1.768
	0.152	1.757	0.162	1.748	0.165	1.763
	0.172	1.733	0.169	1.737	0.179	1.735
	0.190	1.688	0.185	1.694	0.201	1.668
	0.100	1.640	0.128	1.687	0.131	1.698
	0.113	1.663	0.141	1.740	0.144	1.741
6	0.132	1.712	0.151	1.761	0.155	1.751
	0.149	1.775	0.159	1.722	0.161	1.768
	0.166	1.742	0.172	1.730	0.168	1.749
	0.182	1.706	0.183	1.707	0.180	1.714
	0.133	1.756	0.132	1.758	0.131	1.73
	0.143	1.791	0.141	1.788	0.136	1.768
10	0.148	1.795	0.141	1.808	0.139	1.796
	0.149	1.789	0.147	1.817	0.144	1.802
	0.153	1.775	0.157	1.793	0.156	1.797
	0.166	1.745	0.164	1.772	0.166	1.761
	0.120	1.751	0.125	1.756	0.125	1.764
	0.129	1.797	0.132	1.781	0.137	1.786
12	0.137	1.813	0.140	1.783	0.146	1.806
	0.144	1.793	0.148	1.798	0.150	1.807
	0.151	1.780	0.155	1.788	0.160	1.769
	0.162	1.730	0.169	1.751	0.169	1.742
	0.104	1.806	0.119	1.706	0.133	1.705
	0.115	1.828	0.128	1.724	0.138	1.733
1^+	0.128	1.858	0.136	1.754	0.150	1.775
	0.143	1.853	0.149	1.788	0.166	1.782
	0.155	1.800	0.176	1.745	0.186	1.723
	0.177	1.756	0.198	1.697	0.199	1.680

1^+ Repeated treatment no. 1

Table 9A: Compactability determinations for the surface layer (1 to 9cm) of five treatments with correlation coefficient (R) and standard error ($S_{y \cdot x}$).

Treatment and block no.	Maximum compaction (g/cm^3)	Optimum water content (g/g)	R	$S_{y \cdot x}$	Regression formula
1:B4	1.847	0.142	0.938	0.016	$Y = -0.350 + 31.052X - 109.704X^2$
1:B5	1.748	0.164	0.916	0.013	$Y = -0.661 + 29.445X - 90.014X^2$
1:B6	1.769	0.166	0.973	0.017	$Y = -0.295 + 24.621X - 73.458X^2$
3:B4	1.752	0.160	0.983	0.009	$Y = -0.111 + 23.340X - 73.125X^2$
3:B5	1.745	0.156	0.988	0.006	$Y = 0.414 + 17.125X - 55.07X^2$
3:B6	1.763	0.163	0.967	0.014	$Y = -0.094 + 22.737X - 69.569X^2$
6:B4	1.747	0.153	0.938	0.022	$Y = 0.719 + 13.489X - 44.152X^2$
6:B5	1.764	0.157	0.973	0.010	$Y = -0.544 + 29.442X - 93.903X^2$
6:B6	1.759	0.158	0.978	0.007	$Y = -0.408 + 27.468X - 87.027X^2$
10:B4	1.790	0.148	0.948	0.009	$Y = -1.276 + 41.578X - 140.957X^2$
10:B5	1.812	0.149	0.934	0.010	$Y = -2.309 + 55.450X - 186.531X^2$
10:B6	1.811	0.150	0.979	0.008	$Y = -3.019 + 64.450X + 215.000X^2$
12:B4	1.806	0.139	0.982	0.008	$Y = -1.057 + 41.336X - 149.176X^2$
12:B5	1.794	0.146	0.972	0.006	$Y = 0.037 + 24.010X - 82.028X^2$
12:B6	1.802	0.145	0.959	0.009	$Y = -0.418 + 30.731X - 106.358X^2$
1:B4+	1.849	0.133	0.958	0.014	$Y = 0.972 + 13.225X - 49.878X^2$
1:B5+	1.776	0.157	0.955	0.013	$Y = 0.538 + 15.807X - 50.415X^2$
1:B6+	1.780	0.162	0.981	0.010	$Y = -0.329 + 24.975X - 79.963X^2$

+Analysis was repeated for treatment no. 1. Y = bulk density (g/cm^3), X = water content (g/g).

Table 10A: Regression analysis, maximum compaction, and optimum water content for compaction for the surface layer (1 to 9 cm depth) of five treatments. The data were obtained by taking all points for 3 blocks for each treatment.

Treatment no.	Maximum compaction (g/cm^3)	Optimum water content (g/g)	R	$S_{y \cdot x}$	Regression formula
1	1.782	0.134	0.655	0.051	$Y = 1.331 + 6.706X - 24.970X^2$
3	1.749	0.160	0.921	0.015	$Y = 0.300 + 18.099X - 56.550X^2$
6	1.749	0.155	0.896	0.018	$Y = 0.679 + 13.823X - 44.627X^2$
10	1.802	0.149	0.881	0.012	$Y = -2.048 + 51.707X - 173.606X^2$
12	1.798	0.143	0.826	0.015	$Y = -0.015 + 25.368X - 88.789X^2$
1+	1.783	0.130	0.523	0.048	$Y = 1.483 + 4.609X - 17.717X^2$

+ Repeated treatment 1, Y = bulk density (g/cm^3), X = water content (g/g).

Table 11A: Grain sorghum yield (bu/acre) during 1973 through 1976. Yields are reported at 12.5% moisture content.

Treatment no.	1973 Block 4	1973 Block 5	1973 Block 6	1974 Block 4	1974 Block 5	1974 Block 6
	(bu/acre)					
1	47.6	55.3	81.9	33.8	48.6	36.7
3	69.3	70.0	92.8	67.7	61.1	69.3
6	97.6	101.1	90.2	63.3	67.0	63.5
10	70.7	68.5	76.8	53.2	59.0	86.5
12	43.6	70.0	62.4	20.2	31.5	31.1
	1975			1976		
1	27.9	37.7	35.4	104.6	85.1	95.9
3	52.5	43.2	56.7	142.8	132.2	132.8
6	45.5	36.3	37.5	127.4	131.6	131.9
10	57.3	59.6	64.1	138.4	142.7	148.1
12	35.6	31.8	37.9	61.8	63.7	64.8

Although the treatments were not randomized within blocks, analyses of variance were conducted to evaluate if any significant differences existed within soil physical properties created by the treatments. Analyses of variance were made by regarding the experimental design as a split block design rather than a strip block design (24), which has no correct analyses. An analysis of variance was determined for each soil physical property and for each soil layer (depth being an independent variable) (Tables 12A through 22A). Some soil physical properties of the surface layer only were studied, and their analyses of variance are given in Tables 23A through 26A. An analysis of variance of grain sorghum yields was made using treatments and blocks as the dependent variables in each of the four years (Table 27A). Another analysis of variance of grain sorghum yields was made by taking the mean of three blocks and using treatments and years as the dependent variables (Table 28A).

Table 12A: Analysis of variance of organic matter content for each depth layer.

Layer	Source of variation	SS	DF	MS	F	L.S.D. 0.05
1-9 cm	Treatments	0.073	4	0.018	0.31	NS
	Blocks	0.201	2	0.101	1.68	NS
	Error	0.479	8	0.060		
	Total	0.753	14			
16-24 cm	Treatments	0.087	4	0.022	0.48	NS
	Blocks	0.009	2	0.005	0.10	NS
	Error	0.357	8	0.045		
	Total	0.453	14			
31-39 cm	Treatments	0.037	4	0.009	0.09	NS
	Blocks	0.172	2	0.086	0.84	NS
	Error	0.815	8	0.102		
	Total	1.024	14			

Table 13A: Analysis of variance of bulk density for each depth layer.

Layer	Source of variation	SS	DF	MS	F	L.S.D. 0.05
1-9 cm	Treatments	0.007	4	0.002	1.00	NS
	Blocks	0.009	2	0.004	2.37	NS
	Error	0.014	8	0.002		
	Total	0.030	14			
16-24 cm	Treatments	0.029	4	0.007	3.67	NS
	Blocks	0.003	2	0.002	0.87	NS
	Error	0.016	8	0.002		
	Total	0.048	14			
31-39 cm	Treatments	0.008	4	0.002	0.61	NS
	Blocks	0.008	2	0.004	1.12	NS
	Error	0.028	8	0.004		
	Total	0.044	14			

Table 14A: Analysis of variance of penetrometer resistance for each depth.

Depth	Source of variation	SS	DF	MS	F	L.S.D. 0.05
1 cm	Treatments	24.325	4	6.081	3.20	NS
	Blocks	2.481	2	1.240	0.65	NS
	Error	15.221	8	1.903		
	Total	42.026	14			
16 cm	Treatments	137.387	4	34.347	4.82*	5.03
	Blocks	51.671	2	25.835	3.63	NS
	Error	56.983	8	7.123		
	Total	246.040	14			
31 cm	Treatments	24.975	4	6.244	2.28	NS
	Blocks	31.912	2	15.956	5.84*	2.41
	Error	21.871	8	2.734		
	Total	78.759	14			

Table 15A: Analysis of variance of clay content for each depth layer.

Layer	Source of variation	SS	DF	MS	F	L.S.D. 0.05
1-9 cm	Treatments	54.863	4	13.716	2.54	NS
	Blocks	49.828	2	24.914	4.62*	3.39
	Error	43.185	8	5.398		
	Total	147.876	14			
16-24 cm	Treatments	17.391	4	4.348	0.39	NS
	Blocks	82.404	2	41.202	3.65	NS
	Error	90.309	8	11.289		
	Total	190.104	14			
31-39 cm	Treatments	336.270	4	84.067	0.68	NS
	Blocks	975.562	2	487.781	3.93	NS
	Error	992.079	8	124.010		
	Total	2303.909	14			

Table 16A: Analysis of variance of silt content for each depth layer.

Layer	Source of variation	SS	DF	MS	F	L.S.D. 0.05
1-9 cm	Treatments	185.280	4	46.320	4.21	6.25
	Blocks	21.903	2	10.952	0.99	NS
	Error	88.097	8	11.012		
	Total	295.280	14			
16-24 cm	Treatments	128.417	4	32.104	4.40*	5.09
	Blocks	87.724	2	43.862	6.00*	3.94
	Error	58.503	8	7.313		
	Total	274.644	14			
31-39 cm	Treatments	182.591	4	45.648	0.75	NS
	Blocks	278.184	2	139.092	2.30	NS
	Error	484.942	8	60.618		
	Total	945.717	14			

Table 17A: Analysis of variance of sand content for each depth layer.

Layer	Source of variation	SS	DF	MS	F	L.S.D. 0.05
1-9 cm	Treatments	211.470	4	52.867	2.90	NS
	Blocks	130.468	2	65.234	3.58	NS
	Error	145.778	8	18.222		
	Total	487.716	14			
16-24 cm	Treatments	182.980	4	45.745	3.03	NS
	Blocks	99.856	2	49.928	3.31	NS
	Error	120.744	8	15.093		
	Total	403.580	14			
31-39 cm	Treatments	103.642	4	25.911	0.92	NS
	Blocks	214.181	2	107.090	3.80	NS
	Error	225.326	8	28.166		
	Total	543.149	14			

Table 18A: Analysis of variance of water content at -5 cm of water pressure potential for each depth layer.

Layer	Source of variation	SS	DF	MS	F	L.S.D. 0.05
1-9 cm	Treatments	0.00564	4	0.00141	0.416	NS
	Blocks	0.00484	2	0.00242	0.714	NS
	Error	0.02709	8	0.00339		
	Total	0.03757	14			
16-24 cm	Treatments	0.00178	4	0.00046	4.622*	0.02
	Blocks	0.00094	2	0.00047	4.884*	0.01
	Error	0.00077	8	0.00010		
	Total	0.00349	14			
31-39 cm	Treatments	0.00313	4	0.00078	0.941	NS
	Blocks	0.00685	2	0.00343	4.118	NS
	Error	0.00665	8	0.00083		
	Total	0.01664	14			

Table 19A: Analysis of variance of water content at -100 cm of water pressure potential for each depth layer.

Layer	Source of variation	SS	DF	MS	F	L.S.D. 0.05
1-9 cm	Treatments	0.00126	4	0.00032	2.016	NS
	Blocks	0.00013	2	0.00006	0.403	NS
	Error	0.00126	8	0.00016		
	Total	0.00265	14			
16-24 cm	Treatments	0.00207	4	0.0052	0.960	NS
	Blocks	0.00178	2	0.00089	1.651	NS
	Error	0.00432	8	0.00054		
	Total	0.00818	14			
31-39 cm	Treatments	0.00536	4	0.00134	0.972	NS
	Blocks	0.01101	2	0.00551	3.991	NS
	Error	0.01104	8	0.00138		
	Total	0.02741	14			

Table 20A: Analysis of variance of water content at -225 cm of water pressure potential for each depth layer.

Layer	Source of variation	SS	DF	MS	F	L.S.D. 0.05
1-9 cm	Treatments	0.00199	4	0.00050	3.255	NS
	Blocks	0.00040	2	0.00020	1.310	NS
	Error	0.00122	8	0.00015		
	Total	0.00362	14			
16-24 cm	Treatments	0.00239	4	0.00060	0.793	NS
	Blocks	0.00242	2	0.00121	1.611	NS
	Error	0.00601	8	0.00075		
	Total	0.01082	14			
31-39 cm	Treatments	0.00663	4	0.00166	0.967	NS
	Blocks	0.01347	2	0.00673	3.912	NS
	Error	0.01377	8	0.00172		
	Total	0.03386	14			

Table 21A: Analysis of variance of water content at -450 cm of water pressure potential for each depth layer.

Layer	Source of variation	SS	DF	MS	F	L.S.D. 0.05
1-9 cm	Treatments	0.00327	4	0.00082	5.230*	0.024
	Blocks	0.00099	2	0.00050	3.166	NS
	Error	0.00125	8	0.00016		
	Total	0.00552	14			
16-24 cm	Treatments	0.00849	4	0.00212	1.594	NS
	Blocks	0.00335	2	0.00167	1.258	NS
	Error	0.01065	8	0.00133		
	Total	0.02248	14			
31-39 cm	Treatments	0.00887	4	0.00222	0.928	NS
	Blocks	0.01835	2	0.00917	3.841	NS
	Error	0.01911	8	0.00239		
	Total	0.04633	14			

Table 22A: Summary of statistical analyses for treatments and blocks at each individual depth with respect to the soil physical properties.

Layer (cm)	Source of variation	Organic matter %	Bulk density (g/cm^3)	Penetrometer[+] resistance (bars)	Soil separates %			Water retention at various pressure potentials			
					Clay	Silt	Sand	-5	-100	-225	-450
1-9	Treatments	NS	NS	NS	NS	*	NS	NS	NS	NS	*
	Blocks	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
16-24	Treatments	NS	NS	*	NS	*	NS	*	NS	NS	NS
	Blocks	NS	NS	NS	NS	*	NS	*	NS	NS	NS
31-39	Treatments	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Blocks	NS	NS	*	NS	NS	NS	NS	NS	NS	NS

+ Measurements were taken at 1 cm, 16 cm, and 31 cm soil depths.

Table 23A: Analysis of variance for the size distribution of aggregates (g dry wt. of aggregates/25 g of soil sample) from the 1-9 cm depth layer.

Source of variation	SS	DF	MS	F	L.S.D. 0.05
	8 mm>Aggregates>2 mm				
Treatments	2.428	4	0.607	2.62	NS
Blocks	1.787	2	0.893	3.85	NS
Error	1.855	8	0.232		
Total	6.069	14			
	2 mm>Aggregates>1 mm				
Treatments	2.175	4	0.544	5.80*	0.58
Blocks	0.530	2	0.265	2.83	NS
Error	0.750	8	0.094		
Total	3.455	14			
	1 mm>Aggregates>0.5 mm				
Treatments	3.371	4	0.483	1.52	NS
Blocks	3.693	2	0.846	3.34	NS
Error	4.428	8	0.554		
Total	11.492	14			
	0.5 mm>Aggregates>0.1 mm				
Treatments	16.318	4	4.079	2.89	NS
Blocks	2.830	2	1.415	1.00	NS
Error	11.312	8	1.414		
Total	30.460	14			
	8.0 mm>Aggregates>0.1 mm				
Treatments	45.804	4	11.451	3.26	NS
Blocks	21.541	2	10.771	3.06	NS
Error	28.132	8	3.517		
Total	95.477	14			

Table 24A: Analysis of variance of consistency limits (UPL, LPL, and PN) for the 1-9 cm soil depth layer.

Source of variation	SS	DF	MS	F	L.S.D. 0.05
	UPL				
Treatments	17.607	4	4.402	5.59*	1.67
Blocks	0.700	2	0.350	0.45	NS
Error	6.297	8	0.787		
Total	24.604	14			
	LPL				
Treatments	1.723	4	0.431	1.00	NS
Blocks	0.437	2	0.218	0.51	NS
Error	3.440	8	0.43		
Total	5.600	14			
	PN				
Treatments	18.184	4	4.546	9.37**	1.81
Blocks	0.287	2	0.143	0.30	NS
Error	7.881	8	0.485		
Total	22.352	14			

Table 25A: Analysis of variance of soil compactibility data for the 1-9 cm soil depth layer.

Source of variation	SS	DF	MS	F	L.S.D. 0.05
	Optimum water (g/g)				
Treatments	0.00062	4	0.00015	4.40*	0.01
Blocks	0.00023	2	0.00011	3.25	NS
Error	0.00028	8	0.000035		
Total	0.00112	14			
	Maximum compaction (g/cm^3)				
Treatments	0.00705	4	0.00176	2.54	NS
Blocks	0.00063	2	0.00031	0.45	NS
Error	0.00556	8	0.00070		
Total	0.01323	14			

Table 26A: Summary of statistical analyses for treatments and blocks with respect to the soil physical properties data.

	Soil compactibility		Soil consistency			Size distribution of aggregates				
	Optimum water	Maximum compaction	UPL	LPL	PN	<8 mm Agg. >2 mm	<2 mm Agg. >1 mm	<1 mm Agg. >0.5 mm	<0.5 mm Agg. >0.1 mm	<8.0 mm Agg. >1.0 mm
Treatments	*	NS	*	NS	**	NS	*	NS	NS	NS
Blocks	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

* = 5% significance level, ** = 1% significance level, NS = not significant.

Table 27A: Analysis of variance of grain sorghum yield in each year of the period 1973 through 1976.

Year	Source of variation	SS	DF	MS	F	L.S.D. 0.05
1973	Treatments	2694.56	4	673.64	5.95*	20.04
	Blocks	567.33	2	283.66	2.50	NS
	Error	906.29	8	113.29		
	Total	4168.18	14			
1974	Treatments	3904.38	4	976.08	12.15**	16.88
	Blocks	241.88	2	120.94	1.50	NS
	Error	642.73	8	80.34		
	Total	4788.99	14			
1975	Treatments	1551.55	4	387.89	16.63***	9.09
	Blocks	53.16	2	26.58	1.14	NS
	Error	186.62	8	23.33		
	Total	1791.33	14			
1976	Treatments	13162.50	4	3290.62	146.18***	8.93
	Blocks	10.90	2	5.45	0.24	NS
	Error	180.09	8	22.51		
	Total	13353.50	14			

Table 28A: Analysis of variance of grain sorghum yield (the mean of three blocks) for the years 1973 through 1976.

Source of variation	SS	DF	MS	F	L.S.D. 0.05
Treatments	4563.13	4	1140.78	6.33**	20.68
Years	14450.64	3	4816.88	26.73***	18.50
Error	2162.44	12	180.20		
Total	21176.21	19			

Statistical analyses were carried out using techniques for a split block design (24) although the experimental design was strip block design and the treatments were arranged in a sequence identical in each of the three blocks rather than at random. With this sort of design, which has no correct analyses, it seemed desirable to perform some statistical analyses by approximation to split block design. Analyses of variance were conducted to evaluate if any significant differences existed between treatments, blocks, and depths for each soil physical property (depth being a dependent variable) (Tables 29A through 34A).

Because the treatments were not randomized within each block and there was no more than one spot sampled from each plot in each of the three blocks, no interaction between treatments and blocks could be found and this term is the error term for finding the "F" values of treatments and blocks regardless of the depth being dependent or independent variable.

Table 29A: Analysis of variance of the organic matter content (depth considered a variable).

Source of variation	SS	DF	MS	F	L.S.D. 0.05
Treatments	0.157	4	0.039	0.29	NS
Blocks	0.227	2	0.114	0.86	NS
Trts. x Blocks	1.057	8	0.132		
Depth	2.248	2	1.124	30.32**	0.15
Trts. x Depth	0.043	8	0.005	0.14	NS
Blocks x Depth	0.156	4	0.039	1.05	NS
Error	0.593	16	0.037		
Total	4.479	44			

Table 30A: Analysis of variance of the bulk density data (g/cm^3) (depth considered a variable).

Source of variation	SS	DF	MS	F	L.S.D. 0.05
Treatments	0.0229	4	0.0057	1.75	NS
Blocks	0.0043	2	0.0022	0.66	NS
Trts. x Blocks	0.0261	8	0.0033		
Depths	0.1265	2	0.0632	31.42**	0.035
Trts. x Depths	0.0219	8	0.0027	1.36	NS
Blocks x Depth	0.0156	4	0.0039	1.93	NS
Error	0.0322	16	0.0020		
Total	0.2495	44			

*, **, ***, significant at 0.05, 0.01, 0.001, respectively.

NS: not significant.

Table 31A: Analysis of variance of penetrometer resistance data (bars) (depth considered a variable).

Source of variation	SS	DF	MS	F	L.S.D. 0.05
Treatments	126.24	4	31.56	4.87*	4.79
Blocks	44.49	2	22.24	3.43	NS
Trts. x Blocks	51.87	8	6.48		
Depths	420.56	2	210.28	79.71**	1.26
Trts. x Depths	60.45	8	7.56	2.86*	2.81
Blocks x Depths	41.57	4	10.39	3.94*	2.18
Error	42.21	16	2.64		
Total	787.39	44			

Table 32A: Analysis of variance of water content (cm^3/cm^3) at various pressure potential values (-cm of water) (depth considered a variable).

Source of variation	-5 cm of water				L.S.D. 0.05
	SS	DF	MS	F	
Treatments	0.0019	4	0.0005	0.21	NS
Blocks	0.0016	2	0.0008	0.34	NS
Trts. x Blocks	0.0182	8	0.0023		
Depths	0.0043	2	0.0021	2.09	NS
Trts. x Depths	0.0087	8	0.0011	1.06	NS
Blocks x Depths	0.0111	4	0.0028	2.71	NS
Error	0.0163	16	0.0010		
Total	0.0620	44			

Table 32A: (Continued)

Source of variation	SS	DF	MS	F	L.S.D. 0.05
	-100 cm of water				
Treatments	0.0051	4	0.0013	0.98	NS
Blocks	0.0082	2	0.0041	3.14	NS
Trts. x Blocks	0.0104	8	0.0013		
Depths	0.0189	2	0.0094	24.35**	0.02
Trts. x Depths	0.0036	8	0.0005	1.17	NS
Blocks x Depths	0.0047	4	0.0012	3.06*	0.026
Error	0.0062	16	0.0004		
Total	0.0571	44			
	-225 cm of water				
Treatments	0.0080	4	0.0020	1.28	NS
Blocks	0.0113	2	0.0056	3.61	NS
Trts. x Blocks	0.0125	8	0.0016		
Depths	0.0283	2	0.0141	26.56**	0.02
Trts. x Depths	0.0030	8	0.0004	0.70	NS
Blocks x Depths	0.0050	4	0.0013	2.35	NS
Error	0.0085	16	0.0005		
Total	0.0766	44			
	-450 cm of water				
Treatments	0.0158	4	0.0039	1.69	NS
Blocks	0.0166	2	0.0083	3.56	NS
Trts. x Blocks	0.0187	8	0.0023		
Depths	0.0411	2	0.0206	26.67**	0.02
Trts. x Depths	0.0049	8	0.0006	0.79	NS
Blocks x Depths	0.0061	4	0.0015	1.97	NS
Error	0.0123	16	0.0008		
Total	0.1155	44			

Table 33A: Analysis of variance of percentages clay, silt, and sand data (depth considered a variable).

Source of variation	Clay				
	SS	DF	MS	F	L.S.D. 0.05
Treatments	193.59	4	48.40	0.57	NS
Blocks	747.06	2	373.53	4.42	NS
Trts. x Blocks	676.05	8	84.51		
Depths	1564.30	2	782.15	27.84**	4.10
Trts. x Depths	214.93	8	26.87	0.96	NS
Blocks x Depths	360.73	4	90.18	3.21*	7.11
Error	449.53	16	28.10		
Total	4206.19	44			
	Silt				
Treatments	171.83	4	42.96	1.07	NS
Blocks	101.86	2	50.93	1.26	NS
Trts. x Blocks	332.33	8	40.29		
Depths	678.79	2	339.39	17.67**	3.40
Trts. x Depths	324.46	8	40.56	2.10	NS
Blocks x Depths	285.95	4	81.49	3.70*	5.89
Error	309.22	16	19.33		
Total	2194.43	44			
	Sand				
Treatments	397.05	4	99.26	2.07	NS
Blocks	345.47	2	172.73	3.60	NS
Trts. x Blocks	384.06	8	48.01		
Depths	182.78	2	91.39	13.57*	2.01
Trts. x Depths	101.04	8	12.63	1.88	NS
Blocks x Depths	94.04	4	24.76	3.68*	3.48
Error	107.79	16	6.74		
Total	1617.22	44			

Table 34A: Summary of statistical analyses for treatments, blocks, depths, and their interactions with respect to the soil physical properties.

Source of variation	Organic matter %	Bulk density (g/cm^3)	Penetrometer resistance (bars)	Soil separates %			Water content at various pressure potentials (cm^3/cm^3)			
				Clay	Silt	Sand	-5	-100	-225	-450
Treatments	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
Blocks	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Depths	**	**	**	**	**	**	NS	**	**	**
Trts. x Depths	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
Blocks x Depths	NS	NS	*	*	*	*	NS	*	NS	NS

* = 5% significance level, ** = 1% significance level, NS = not significant.

INFLUENCE OF LONG-TERM SOIL AMENDMENTS ON PHYSICAL PROPERTIES OF CHEROKEE SILT LOAM

by

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AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1978

ABSTRACT

A study of the influence of soil amendments on physical properties of a Cherokee silt loam soil was initiated in 1923. The study was located on the Columbus field of the Southeast Kansas Branch Experiment Station. A multiple year crop rotation scheme was superimposed over the amendment treatments. The amendment treatments sampled for the thesis study were 1 (lime), 3 (lime, superphosphate, potash; with legume in rotation), 6 (lime, manure), 10 (lime, superphosphate, potash; with no legume in rotation), and 12 (check). Disturbed and undisturbed soil samples were taken in September, 1976, from the 1 to 9, 16 to 24, and 31 to 39 cm soil layers.

Analyses of variance showed no significant differences in organic matter content or in soil bulk density between treatments in each of the three soil layers (5% level). There were significant differences among treatments in penetrometer resistance at the 16 cm depth (5% level). The analyses of variance of soil separates for the treatments revealed that only the silt content in the 1 to 9 and 16 to 24 cm layers was significantly different at the 5% level. Significant differences in water content were found among treatments only in the 1 to 9 cm layer at -450 cm of water pressure potential and in the 16 to 24 cm layer at -5 cm of water pressure potential (5% level). Some soil physical properties were studied for the 1 to 9 cm layer only and the analyses of variance of the data revealed the following:

- The 1 to 2 mm size aggregates of treatments were significantly different at the 5% level.
- The upper plastic limit and plasticity number were significantly different among treatments at the 5% level.
- A significant difference was found between treatments in the optimum water content for compaction, but there was no significant difference in the maximum compaction values at the 5% level.

Grain sorghum was planted after discontinuing the amendment applications to evaluate the residual effects of the amendments on crop yield. An analysis of variance showed significant differences in the yield between treatments (5% level) during each year (1973 to 1976) as well as for the four-year mean. Treatments 10, 6, and 3 had the largest grain yields. They had significantly greater yield than treatments 1 and 12. Treatment 12 (check) had the lowest four-year yield of the five treatments studied. Therefore, the amendments have caused subsequent grain sorghum yield advantages either by chemical or by physical means. It appears the amendment materials had more influence upon yield increases through chemical than through physical processes.